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DESIGN AND CONSTRUCTION OF CONTINUOUSLY REINFORCED CONCRETE AIRPORT PAVEMENTS.

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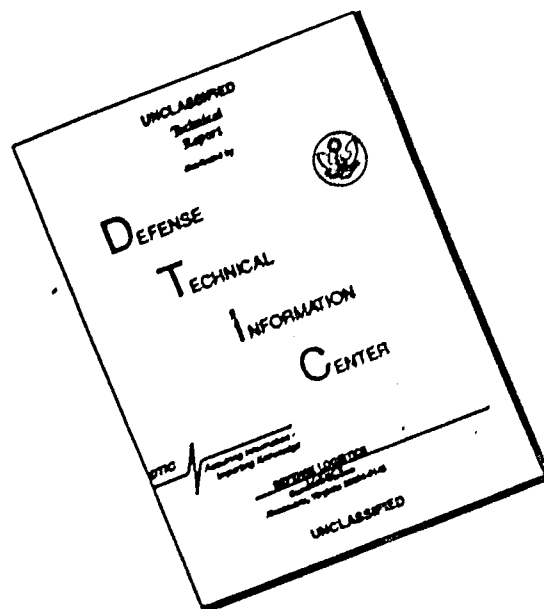FINAL REPORT.,

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16. Abstract

This report provides design procedures for continuously reinforced concrete (CRC) airport pavements. The basic physical-mathematical model and applicable analyses are discussed. Thickness design procedures for both new CRC pavements and CRC overlays are presented for both civil and military aircraft. Methods for designing steel reinforcement, construction joints, and terminal treatment systems are included. All of these procedures are recommended for immediate use.

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PREFACE

This report was prepared by the U. S. Army Engineer Waterways Experiment Station (WES) as a part of an investigation funded by the Federal Aviation Administration (FAA), U. S. Department of Transportation, under Inter-Agency Agreement FA71WAI-218, and the Office, Chief of Engineers (OCE), as part of Project AT 40: Research in Pavements, Soils, and Foundations, Task 02: Pavement Structural Capabilities and Functional Requirements Analysis. The purpose of the study reported herein was to develop criteria for the design of continuously reinforced concrete airport/airfield pavements. Prior studies were conducted by Austin Research Engineers, Inc. (ARE), Austin, Texas, and the results published as Report No. FAA-RD-73-33, Volumes I-IV (WES MP S-74-22), and WES Contract Report S-76-11.

The investigation was conducted during the period June 1974 - June 1976 under the general supervision of Messrs. J. P. Sale and R. G. Ahlvin, Chief and Assistant Chief, respectively, of the Soils and Pavements Laboratory (S&PL). Mr. Gary G. Harvey of the Pavement Design Division (PDD) was the principal investigator and authored this report.

COL G. H. Hilt, CE, and COL J. L. Cannon, CE, were Directors and Mr. F. R. Brown was Technical Director of WES during the study and preparation of this report.

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METRIC CONVERSION FACTORS

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm²	square centimeters	0.16	square inches	in²
m²	square meters	1.2	square yards	yd²
km²	square kilometers	0.4	square miles	mi²
ha	hectares (10,000 m²)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m³	cubic meters	35	cubic feet	ft³
m³	cubic meters	1.3	cubic yards	yd³
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in²	square inches	6.5	square centimeters	cm²
ft²	square feet	0.09	square meters	m²
yd²	square yards	0.8	square meters	m²
mi²	square miles	2.6	square kilometers	km²
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft³	cubic feet	0.03	cubic meters	m³
yd³	cubic yards	0.76	cubic meters	m³
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286. Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

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INTRODUCTION

BACKGROUND

Continuously reinforced concrete (CRC) pavement is a pavement which has continuous steel reinforcement in the longitudinal direction (direction of paving). For airports, the pavement is placed in strips (one paving lane wide) separated by conventional longitudinal construction joints. Transverse cracks develop but are held tightly closed by the longitudinal steel. Transverse joints are eliminated, except for transverse construction joints. Reinforcing steel is continuous through transverse construction joints, and these joints function in essentially the same way as the transverse cracks. Provision for adequate longitudinal steel to minimize the transverse crack widths and to prevent the widening of the cracks is a basic principle of design for CRC pavement. Full load transfer is maintained across the cracks. The absence of transverse joints reduces joint maintenance and resealing, and improves the riding quality of the pavement. The reduction in the number of joints in the pavement improves pavement performance, since joints have proved to be the source of much of the distress in rigid pavements.

Another factor which, in certain instances, influences the choice of the type of pavement is the increasing use of slip-form pavers. Formation of the weakened planes for transverse contraction joints with inserts is difficult without some form of support for the pavement edges. The alternative to inserts is sawing, but in some geographic locations sawing has not been satisfactory because the hardness of available aggregate prevents sawing early enough to prevent shrinkage cracking. In these areas CRC offers an alternative which eliminates the need for transverse contraction joints.

CRC has not been used extensively for airport pavements, although the properties of CRC pavement, enumerated previously, should improve the serviceability of a facility for aircraft operation. This should be particularly true at facilities which handle large volumes of traffic where removing a pavement from service is both inconvenient

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and costly. The only significant usage of CRC on airports has been at USAF Plant 42, Palmdale, California, and at Midway and O'Hare International Airports in Chicago, Illinois.[1]

Because of the limited usage of CRC for airport pavements, only a minimal amount of performance data are available. The design for these airport pavements was based on experience with highway pavements and/or modifications to procedures for nonreinforced and reinforced jointed concrete airport pavements.

Highway departments have combined the results from considerable research and experience with local construction and performance data to produce design and construction procedures suited to particular traffic, geographic, and environmental conditions. As a result, each highway department has its own design procedures and construction specifications for CRC pavements. The rather extensive research efforts and experience with highway pavements has resulted in reliable steel design procedures, terminal treatment techniques, and construction procedures. However, only limited research and performance data are available for determining thickness of CRC pavements and overlays for aircraft traffic. Because of differences in functional requirements and loading conditions, the performance criteria for highway pavements are not considered to be directly applicable to the design of airport pavements.

In July 1971, as part of a jointly funded Federal Aviation Administration (FAA) and Office, Chief of Engineers (OCE) investigation, the Waterways Experiment Station (WES) undertook to develop a general design procedure for CRC airport pavements and overlays. FAA and OCE funds were combined with funds from the Air Force Weapons Laboratory (AFWL) and the Austin Research Engineers, Inc. (ARE) were contracted to evaluate the performance of in-service CRC airport pavements and overlays, and to formulate a procedure for the design of CRC airport pavements and overlays based on the results of the evaluation and other available design data. Guidance for the construction of such pavements was also to be provided. This study is reported in a

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four-volume report entitled "Continuously Reinforced Concrete Airfield Pavement."[1] Another contract with ARE included instrumentation of the CRC pavement Runway 4R-22L at O'Hare International Airport, and collection and analysis of response and performance data.[2]

OBJECTIVES

The objectives of this study were to formulate an implementable design procedure for CRC airport pavements and overlays which is compatible with procedures currently used by the FAA and OCE for the design of nonreinforced and reinforced, jointed concrete pavements, and to provide guidance for handling construction problems that are unique to CRC pavements.

SCOPE

Modifications to the procedures developed by ARE[1] have been made as indicated appropriate by the O'Hare study, and as needed to preclude requirements for estimating traffic, characterizing materials, and computing slab thicknesses which are different from those used for other types of pavement. Included in the procedures developed herein are recommended methods for selecting design parameters (traffic estimates and material characteristics), methods for determining slab thickness, methods for designing reinforcing steel, methods for selecting terminal treatment systems, and methods for selecting joint details. Included in the construction guidance are recommended construction details unique to CRC; i.e., details for laps at splices in reinforcing bars, details for transverse construction joints, steel placement, terminal treatment systems, etc.

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TECHNICAL BACKGROUND

CRC pavements, as well as other types of pavement, are complex structures, and this, when combined with the complex nature of loadings produced by an operating aircraft, results in a problem which defies precise analytical solution. Since only a small amount of performance data exists for airports, the modes and causes of failure of CRC pavements are not well established. However, enough is known about CRC pavement performance to allow failure hypotheses to be proffered. Two primary failure modes are strongly indicated and are examined in this chapter. Although there are other modes or causative factors, they are considered to be minor in comparison to cracking due to excessive stress in the slab and spalling due to deflection.

CRC PAVEMENT PERFORMANCE
RELATED TO STRESS

The basic design concept for CRC pavements is to limit the magnitude of the load-induced tensile stress in the slab to an acceptable level. The acceptable stress level is the maximum which can be tolerated without excessive cracking occurring. CRC pavements are composed of variable-sized slabs tied together with reinforcing steel which are formed by cracks caused by shrinkage and/or contraction of the concrete. These cracks are not considered indicative of pavement distress. The shrinkage or contraction cracking occurs soon after construction, and a relatively stable crack pattern develops, as illustrated in Figure 1.[3] As loads are applied additional cracking will develop. These cracks are caused by load-induced stresses and are the basic distress manifestation upon which the design criteria are based.

HYPOTHESIS FOR LIMITING
STRESS CRITERIA

When the bending stress in the slab, due to applied load, exceeds the flexural strength of the portland cement concrete (PCC) a crack will be initiated in the slab at the point of maximum stress. Once a crack has been initiated, it will progress through the slab

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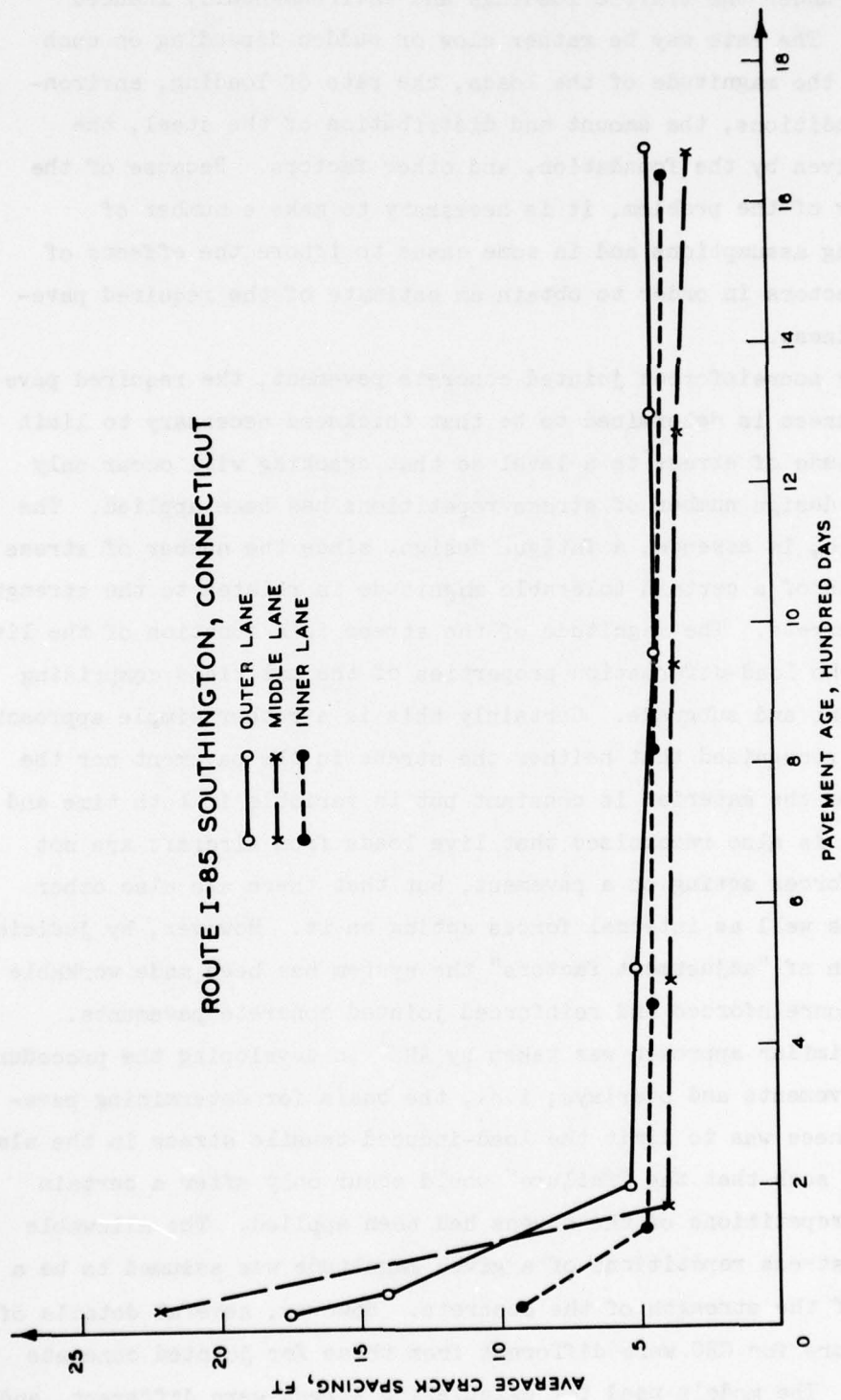
Figure 1. Illustration of crack development with time in a CRC pavement[3]

thickness under the traffic loadings and environmentally induced stresses. The rate may be rather slow or sudden depending on such things as the magnitude of the loads, the rate of loading, environmental conditions, the amount and distribution of the steel, the support given by the foundation, and other factors. Because of the complexity of the problem, it is necessary to make a number of simplifying assumptions and in some cases to ignore the effects of certain factors in order to obtain an estimate of the required pavement thickness.

For nonreinforced jointed concrete pavement, the required pavement thickness is determined to be that thickness necessary to limit the magnitude of stress to a level so that cracking will occur only after the design number of stress repetitions has been applied. The approach is, in essence, a fatigue design, since the number of stress repetitions of a certain tolerable magnitude is related to the strength of the concrete. The magnitude of the stress is a function of the live load and the load-deformation properties of the materials comprising the pavement and subgrade. Certainly this is a rather simple approach, and it is recognized that neither the stress in the pavement nor the strength of the material is constant but is variable in both time and space. It is also recognized that live loads from aircraft are not the only forces acting on a pavement, but that there are also other external as well as internal forces acting on it. However, by judicious application of "adjustment factors" the system has been made workable for both nonreinforced and reinforced jointed concrete pavements.

A similar approach was taken by ARE[1] in developing the procedures for CRC pavements and overlays; i.e., the basis for determining pavement thickness was to limit the load-induced tensile stress in the slab to a value such that the "failure" would occur only after a certain number of repetitions of the stress had been applied. The allowable number of stress repetitions of a given magnitude was assumed to be a function of the strength of the concrete. However, several details of the procedure for CRC were different from those for jointed concrete pavements. The models used for calculating stress were different, and

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there were some differences in the recommended procedures for material characterization.

The failure criteria for CRC proposed by ARE[1] were also different from those currently used for jointed concrete pavements, and are more consistent with criteria for highway pavements than for airport pavements. The criteria are consistent with pavement condition after considerable structural cracking has occurred. When load-induced cracks occur in CRC, they occur between the already relatively closely spaced shrinkage or contraction cracks. This results in continually smaller slabs which may spall and/or pump and eventually leads to a punchout-type failure. This type of failure is illustrated in Figure 2. Diagonal cracking, often referred to as "Y" cracking, may also develop. The mechanism is similar to that illustrated in Figure 2 except the pieces of concrete will be triangular.

It is felt that, for airport pavements, such structural failure criteria as those proposed by ARE[1] would not be consistent with functional airport pavement requirements. Because of this, the limited stress criteria proposed by ARE were not used, but a set of criteria was developed based on nonreinforced jointed concrete pavement experience. These criteria are based on a definition of failure as being the condition at which a limited amount of structural cracking has occurred. The limiting strength-to-stress ratio is dependent on the strength of the foundation and is designed to permit a controlled amount of cracking under applied load repetitions. An attempt has been made to limit the amount of cracking permitted so that other distress manifestations, such as spalling, pumping, and faulting or tilting of individual pieces as often accompanies advanced cracking will not occur. Certainly CRC pavements should be just as tolerant as jointed concrete pavements to some load-induced cracking without a serious loss in serviceability. The steel should keep load-induced cracks closed for a time just as it does the transverse shrinkage or contraction cracks. Transverse steel is needed to keep longitudinal cracks closed as well as an aid in placing longitudinal steel.

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a. Connecting cracks have formed and spalling has begun

b. Spalling is progressing and pumping has begun
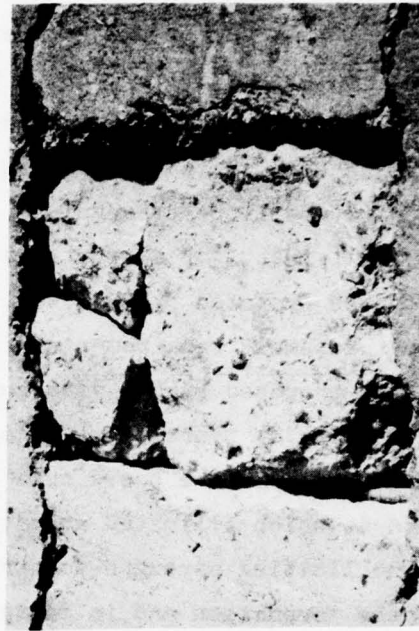
c. Pavement is now broken into several chunks

Figure 2. Progression of cracking in a CRC pavement to a "punchout" failure

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DEVELOPMENT OF LIMITING
STRESS CRITERIA

The limiting stress performance criteria adopted for CRC pavements are modifications of the criteria for nonreinforced jointed concrete pavements for aircraft.[4] The criteria adopted for CRC pavements consist of relationships which reflect a condition of failure between the condition where the slabs are broken into 2 to 3 pieces and the condition where the slabs are broken into about 6 pieces. The criteria (in terms of percent standard thickness and stress repetitions) for these failure conditions for nonreinforced jointed concrete pavements are shown in Figures 3 and 4.

The performance criteria relationships for CRC pavements were obtained by averaging percent standard thickness for certain stress repetition levels, from Figures 3 and 4, and replotting the results as shown in Figure 5. As an example of the computations, percent standard thicknesses of 100 and 92 are obtained, respectively, for the failure condition where slabs are broken into 2 to 3 pieces and the failure condition where the slabs are broken into about 6 pieces, at 10,000 stress repetitions for a k value of 300 psi/in. The average of the two percentages is 96 and is plotted in Figure 5 versus 10,000 stress repetitions. This procedure was followed for a range of stress repetition levels and for k values of 300, 400, and 500 psi/in. The line for k = 25 psi/in. on Figure 4 was combined with the relationship for k ≤ 200 psi/in. on Figure 3 to develop the relationship labeled k ≤ 200 psi/in. on Figure 5.

For certain applications, it is more convenient to express the performance criteria in terms of a design factor, design factor being defined as the ratio of the flexural strength of the concrete to the tensile stress in the concrete. For the methodology for jointed concrete pavements, the stress is computed with a two-layer model (often referred to as the Westergaard algorithm) which describes the pavement as a thin elastic plate on a dense liquid (Winkler) foundation. The stress is the maximum stress which occurs at a free edge of a slab with a 25 percent reduction to account for support provided by

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RIGID PAVEMENT LIFE

TRICYCLE-TYPE GEAR
(2 TO 3 PIECES PER SLAB)

k = MODULUS OF SOIL REACTION

k ≤ 200 PSI/IN.

k = 300 PSI/IN.

400

500

STRESS REPETITIONS

STANDARD THICKNESS, PERCENT
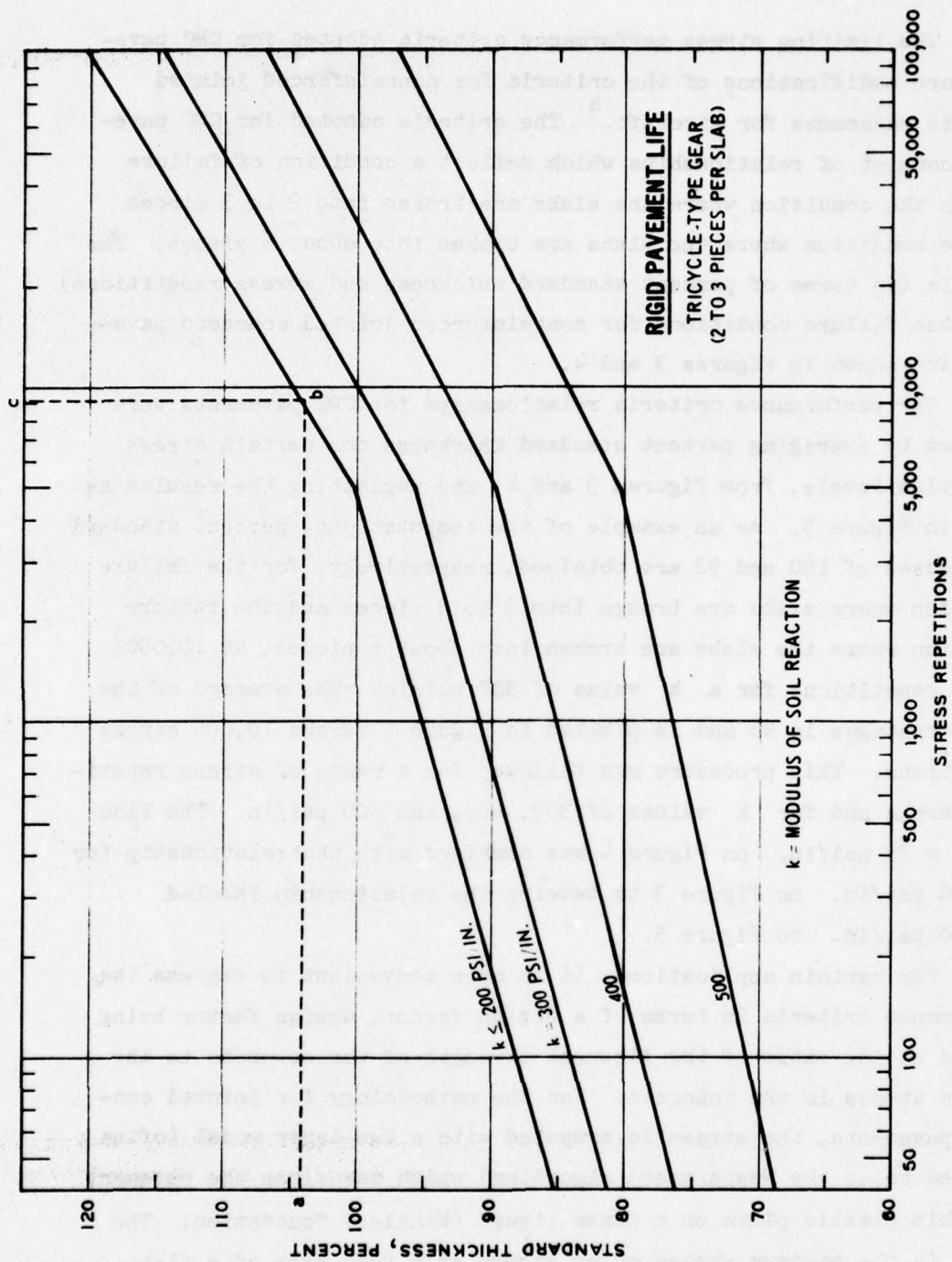
Figure 3. Limiting stress performance criteria for nonreinforced jointed concrete pavements based on initial failure[4]

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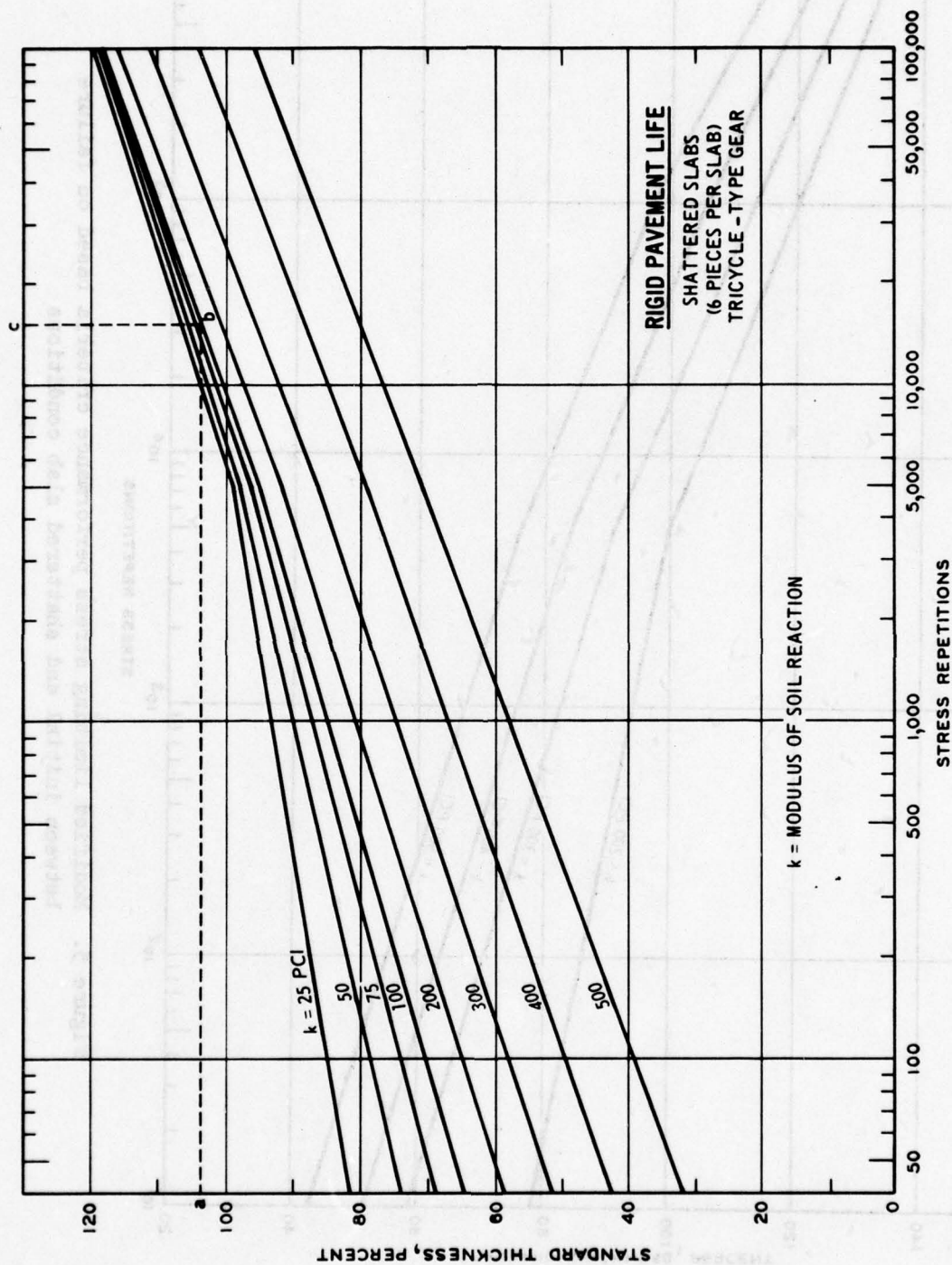
Figure 4. Limiting stress performance criteria for nonreinforced jointed concrete pavements based on shattered slab conditions[4]
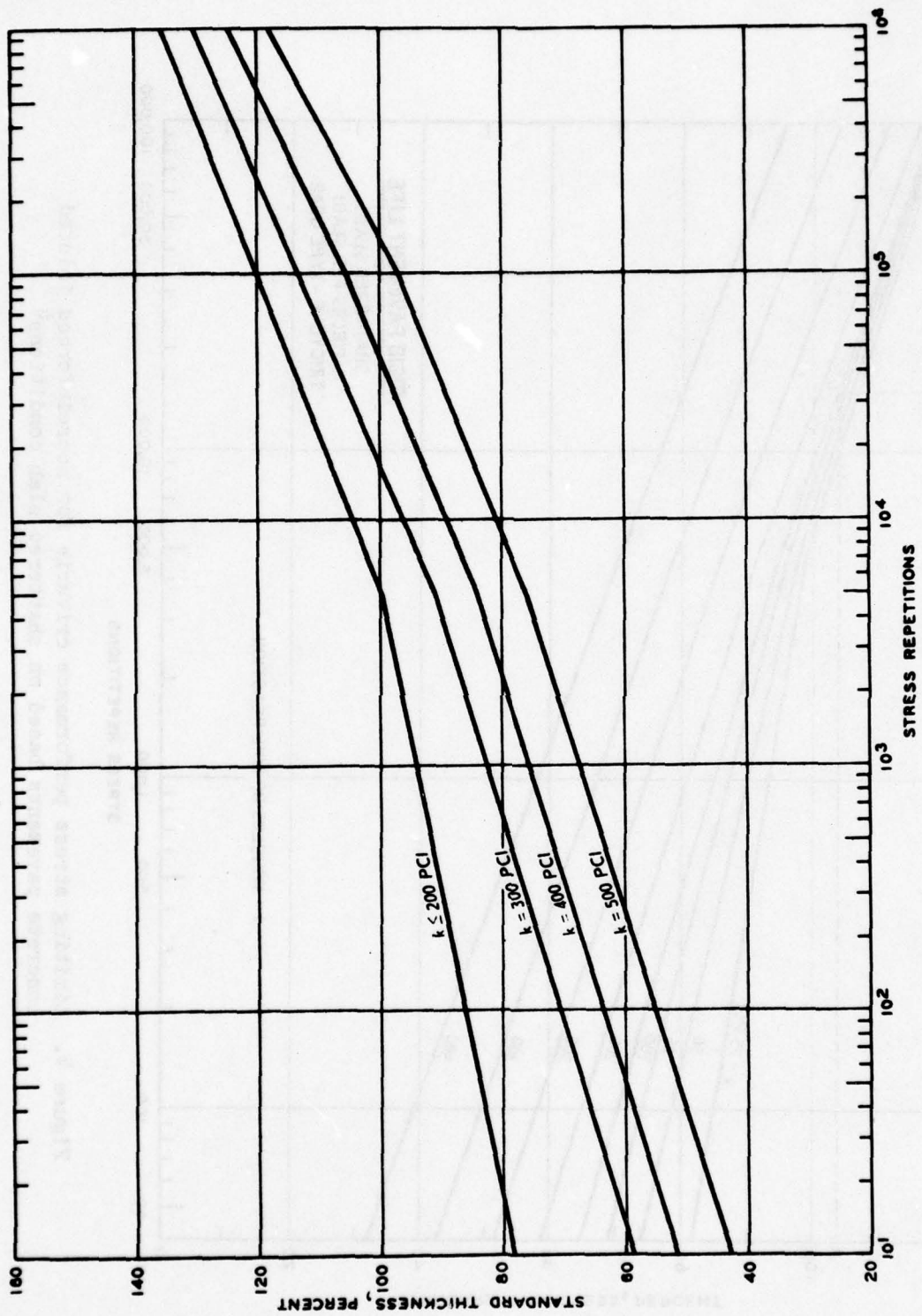
Figure 5. Modified limiting stress performance criteria based on failure between initial and shattered slab conditions

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adjacent slabs. The flexural strength is the strength measured with a simply supported beam loaded at the third points. For jointed concrete pavements standard thickness is the thickness required for 5000 stress repetitions. For k ≤ 200 psi/in. this is the thickness necessary so that the tensile stress in the slab when divided into the flexural strength will equal 1.3; i.e., the design factor equals 1.3. Such relationships have been developed for a range of k values and nonreinforced jointed concrete pavements through full-scale accelerated test tracks.

To make the conversion between design factor and percent standard thickness it was necessary to develop a relationship between the two parameters. This relationship is shown in Figure 6. As can be seen from the scatter in the points there is no unique relationship between design factor and the percent standard thickness, but the relationship will depend on the load, the k value, and the thickness. This is not unexpected, because the relationship between thickness and stress is not a simple linear relationship, but is a complex function which is also dependent on the k value and the loading. The line shown in Figure 6 is simply sketched through the points. The line was restrained through the point where design factor equals 1.3 and percent standard thickness equals 100.

The limiting stress performance criteria relationships shown in Figure 5 were converted to those shown in Figure 7 by direct application of the linear relationship shown in Figure 6. As an example of the computations, the percent standard thickness for k = 400 psi/in. and 5000 stress repetitions from Figure 5 is 84 percent. From Figure 6, the design factor corresponding to an 84 percent standard thickness is 1.04. Figure 7 was developed by repeating this process and plotting the values of design factor and stress repetitions to develop the relationships shown.

The model for computing stress developed by ARE[1] was adopted for use in the procedure described herein. The model uses a two-layer idealization of the pavement similar to the Westergaard model and

NOTE: DATA POINTS FOR A RANGE OF LOADINGS, K VALUES, THICKNESSES, AND FLEXURAL STRENGTHS.

STANDARD THICKNESS, PERCENT
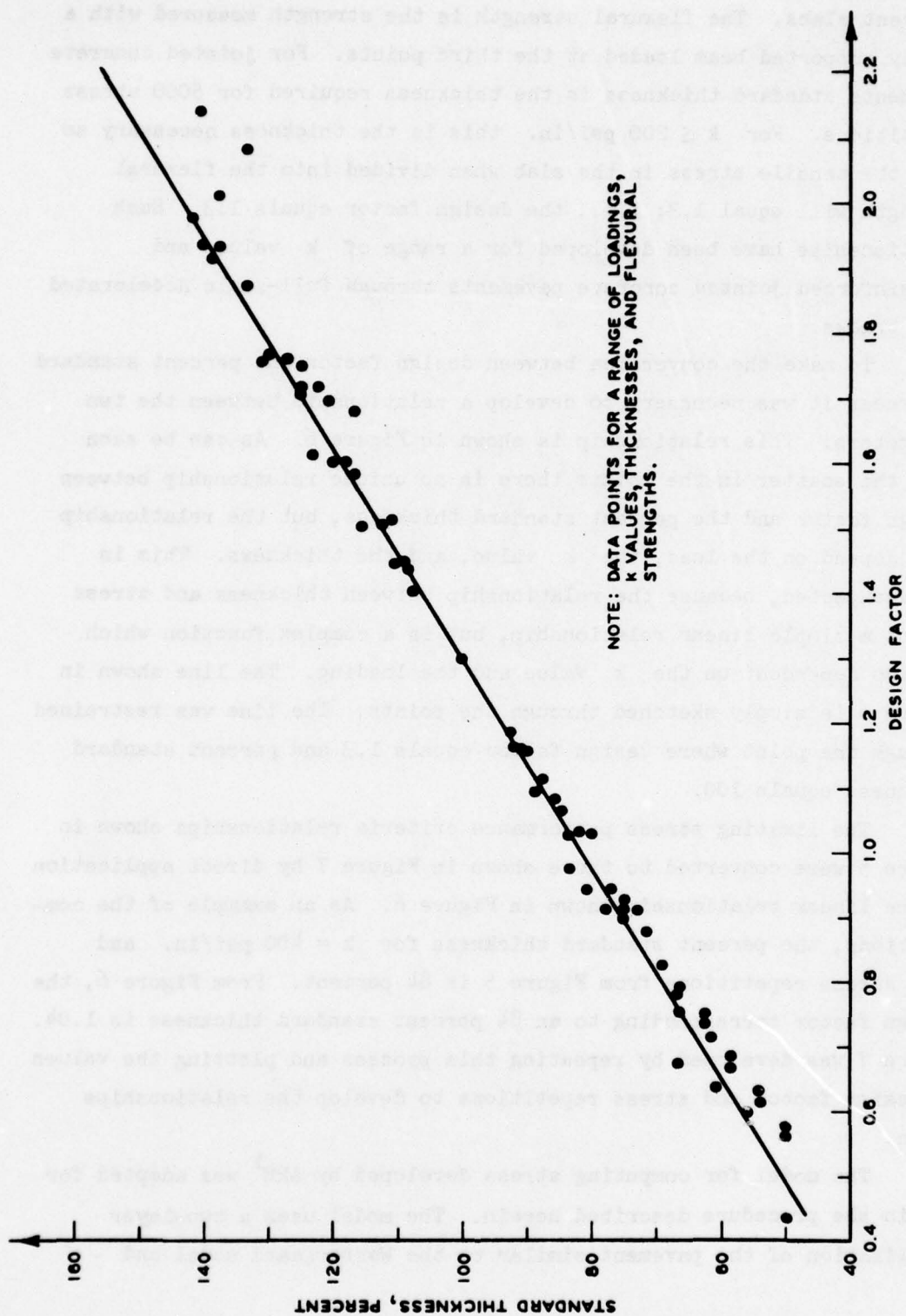
DESIGN FACTOR

Figure 6. Relationship between design factor and percent standard thickness

DESIGN FACTOR

STRESS REPETITIONS

k ≤ 200 PCI

k = 300 PCI

k = 400 PCI

k = 500 PCI

2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6

10^1 10^2 10^3 10^4 10^5 10^6
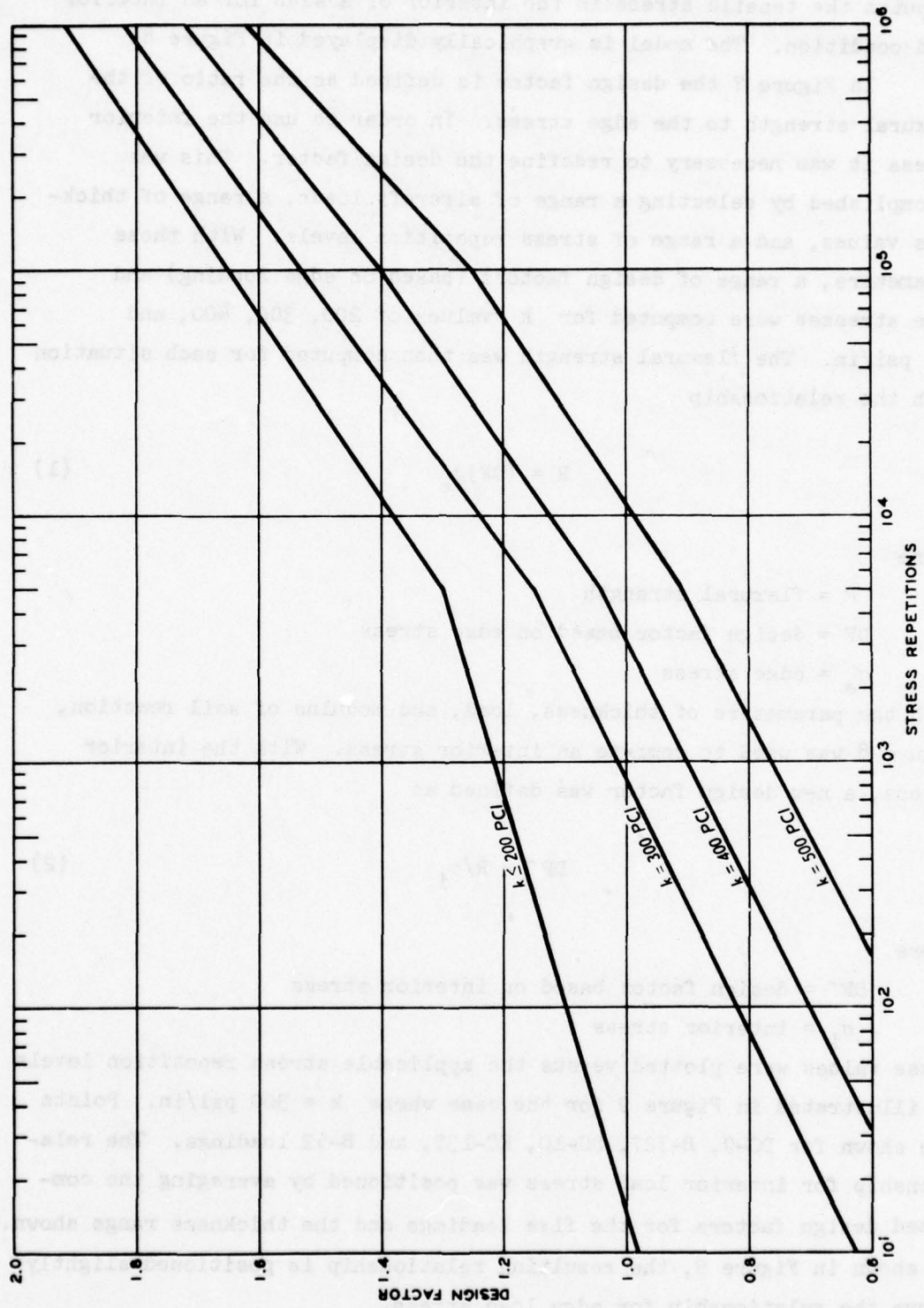
Figure 7. Modified limiting stress performance criteria—design factor format (based on edge loading)

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computes the tensile stress in the interior of a slab for an interior load condition. The model is graphically displayed in Figure 8.

In Figure 7 the design factor is defined as the ratio of the flexural strength to the edge stress. In order to use the interior stress it was necessary to redefine the design factor. This was accomplished by selecting a range of aircraft loads, a range of thickness values, and a range of stress repetition levels. With these parameters, a range of design factors (based on edge loading) and edge stresses were computed for k values of 200, 300, 400, and 500 psi/in. The flexural strength was then computed for each situation with the relationship

$$R = (DF)\sigma_e \tag{1}$$

where

R = flexural strength

DF = design factor based on edge stress

σ_e = edge stress

With the parameters of thickness, load, and modulus of soil reaction, Figure 8 was used to compute an interior stress. With the interior stress, a new design factor was defined as

$$DF' = R/\sigma_i \tag{2}$$

where

DF' = design factor based on interior stress

σ_i = interior stress

These values were plotted versus the applicable stress repetition levels as illustrated in Figure 9 for the case where k = 300 psi/in. Points are shown for DC-9, B-727, DC-10, KC-135, and B-52 loadings. The relationship for interior load stress was positioned by averaging the computed design factors for the five loadings and the thickness range shown. As shown in Figure 9, the resulting relationship is positioned slightly above the relationship for edge load stress.

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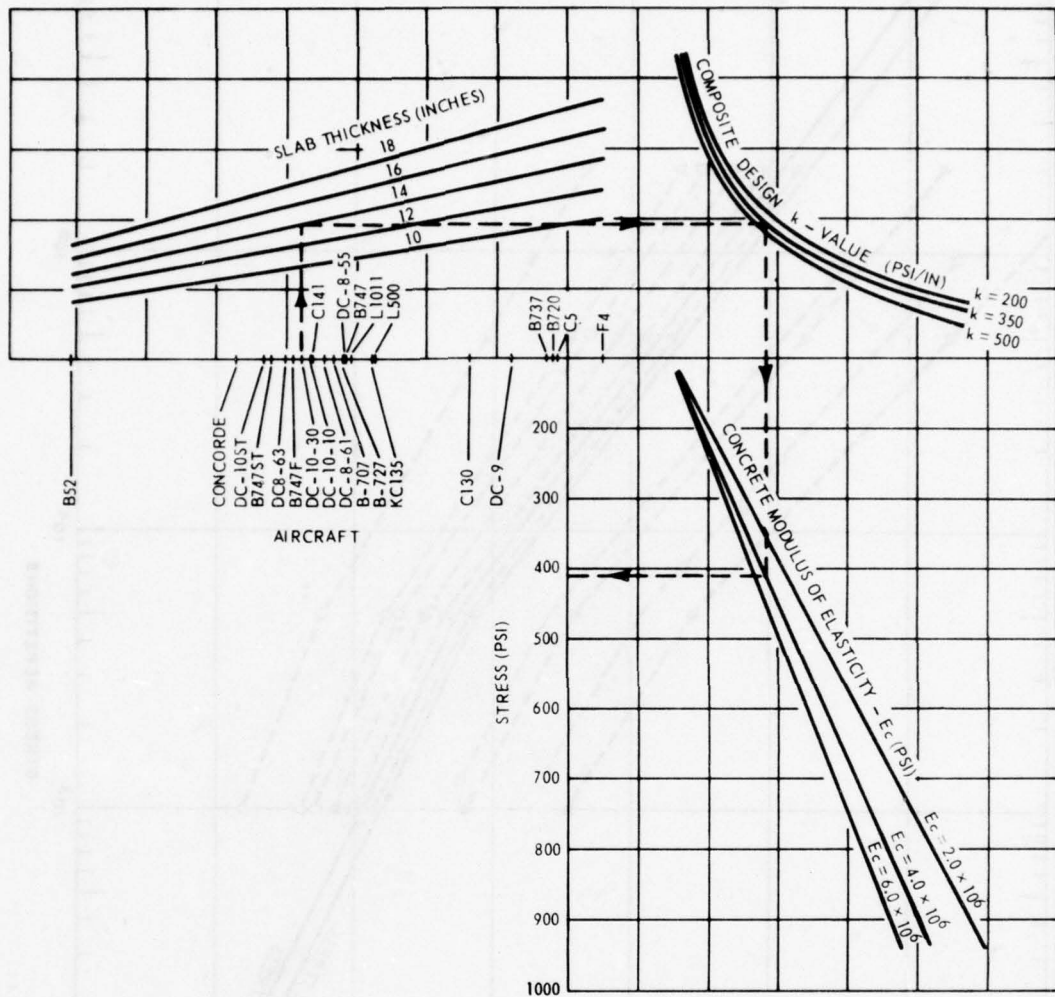
Figure 8. Stress analysis chart[1]
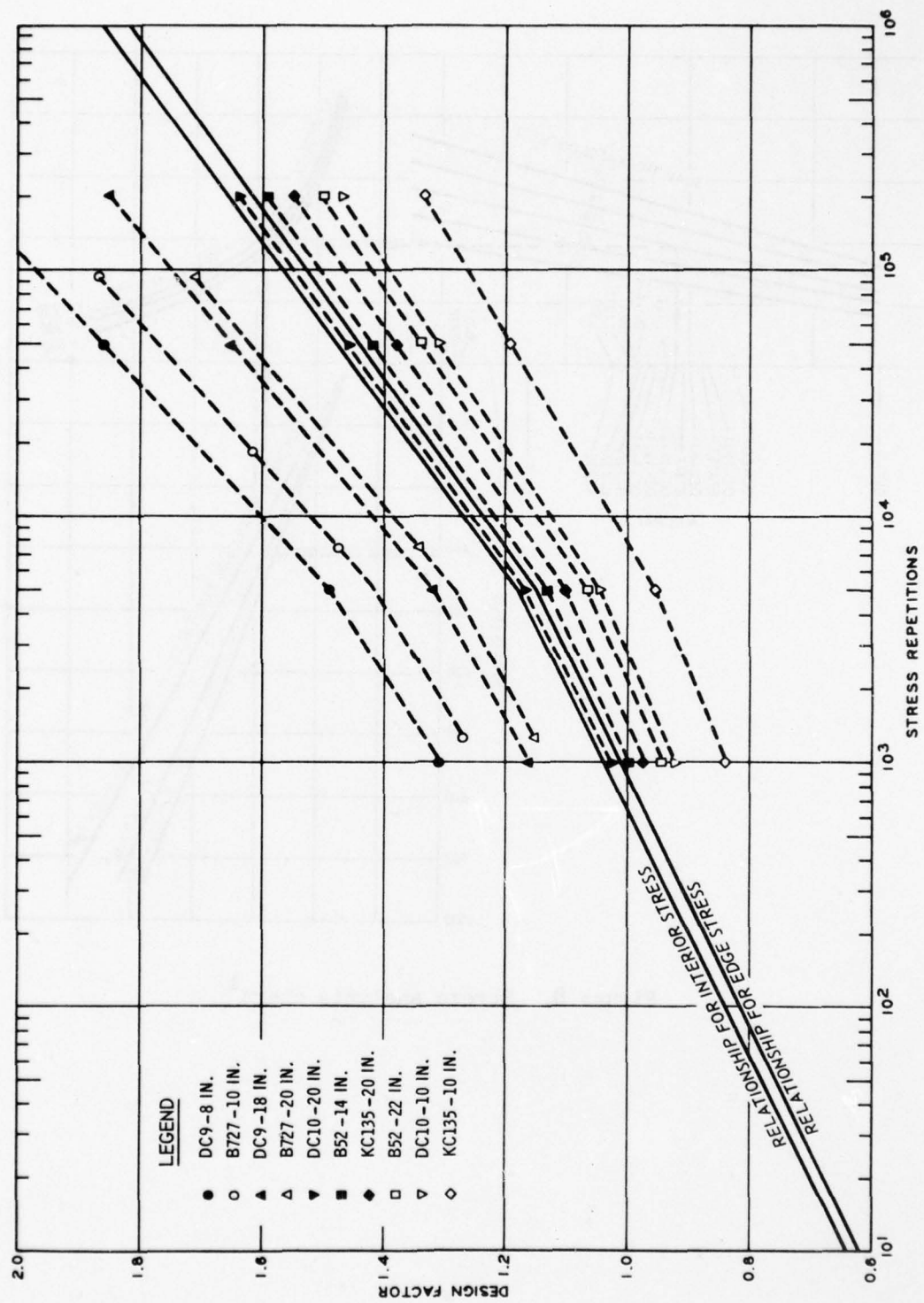
Figure 9. Development of limiting stress performance criteria for CRC pavement, k = 300 psi/in.

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The above-described procedure was repeated for k-values of 200, 400, and 500 psi/in. The resulting limiting stress performance criteria for CRC pavements are shown in Figure 10. These are the criteria adopted for design of CRC pavements and used with the interior stress model illustrated in Figure 8.

ADDITIONAL DISTRESS MECHANISMS

In addition to load-associated cracking, distress in CRC pavements has been observed which cannot be directly related to excessive tensile stress in the concrete. Under certain combinations of foundation strength and loading, a CRC pavement which is adequately designed on the basis of tensile stress in the slab may experience distress because of excessive vertical stress on the foundation which results in vertical deflection. It is generally recognized that excessive deflection of a pavement slab is a possible cause of several types of distress in the pavement--among these are spalling, pumping, added impetus to propagation of existing cracks, and "punchouts."

Probably the most commonly observed manifestation of this kind of distress is spalling at the transverse cracks. CRC pavements designed on the basis of limiting tensile stress have generally in the past been thinner than comparable jointed concrete pavements. Spalling such as is shown in Figure 11 may be the result of increased deflection coupled with reinforcement steel at the cracks which result from reducing the pavement thickness. Experience has shown, however, that jointed concrete pavements designed on the basis of limiting tensile stress will not normally experience premature distress because of such factors as excessive deflection. (Packard[5] and Hutchinson[6] speculate that this may not be valid for large multiple-wheel aircraft on weak foundation.) The problem of excessive deflections is compounded for CRC, because the closely spaced cracks reduce the bending stiffness of the pavement, thereby allowing even larger deflections than a jointed concrete pavement in which comparable bending stresses are produced. This probably accentuates spalling, which can deteriorate and cause functional failure of the pavement prior to the development of

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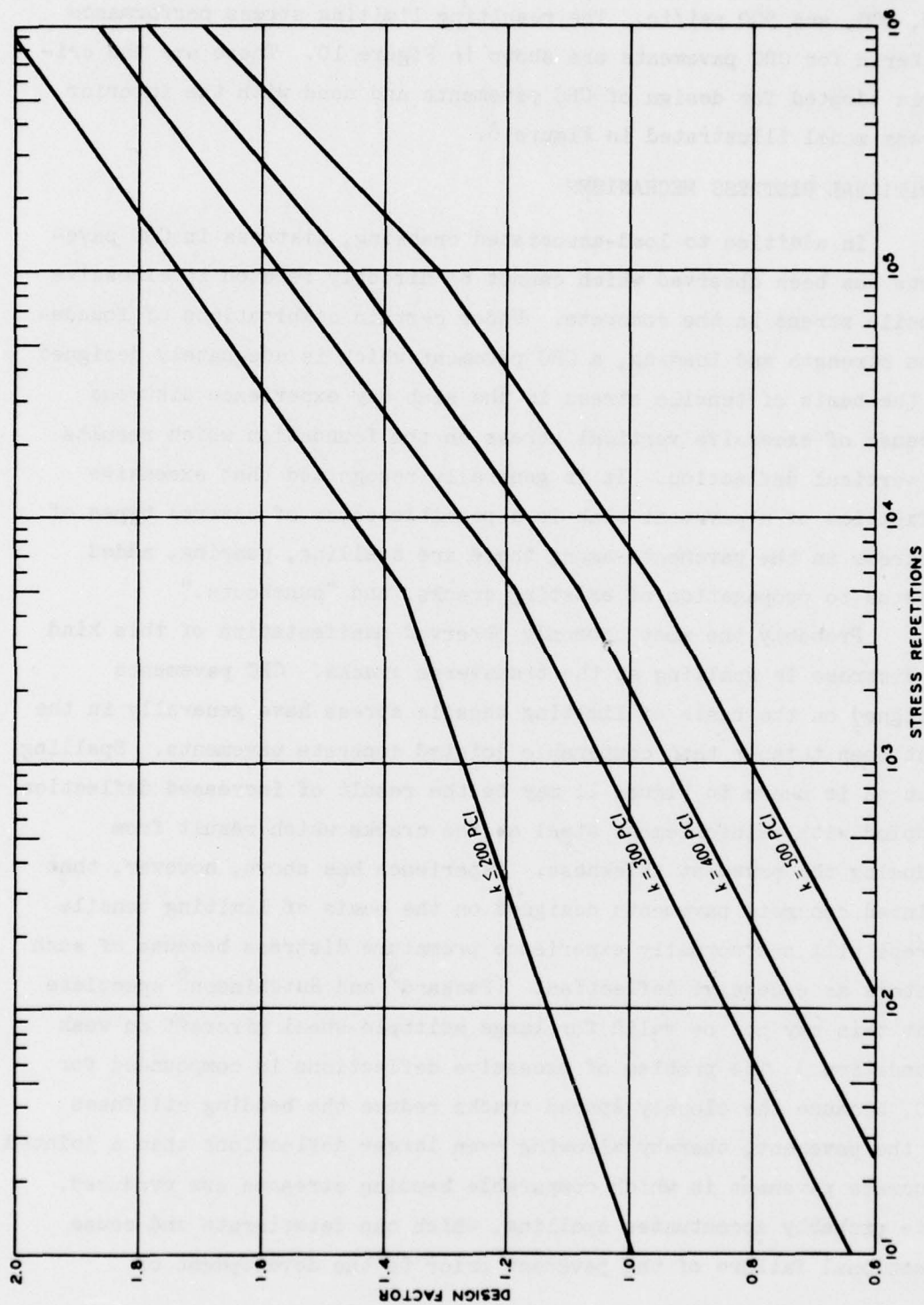
Figure 10. Limiting stress performance criteria for CRC pavements (based on interior loading)
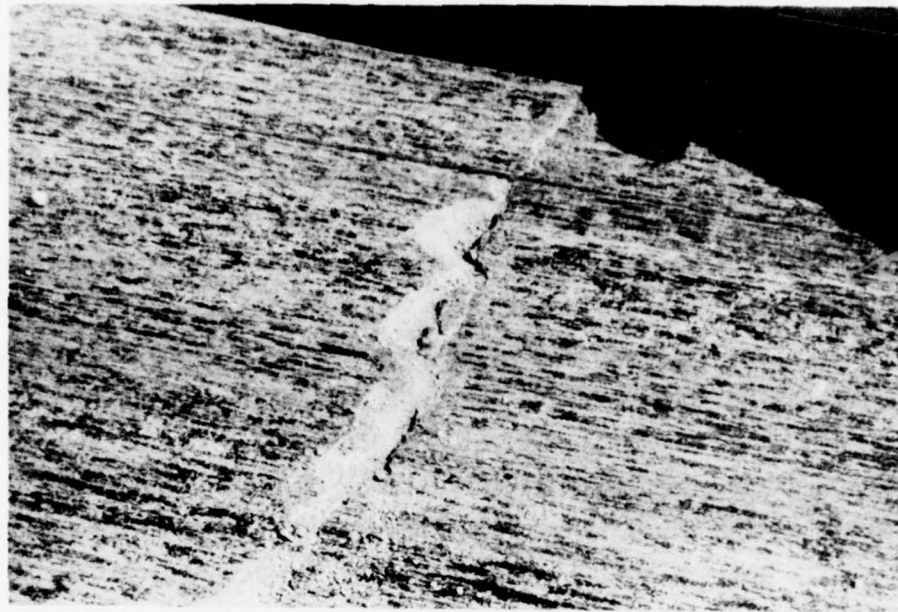
Figure 11. Example of spalling along transverse crack

stress-related cracking. In addition to spalling which can be directly related to live load, spalling which appears to be caused by other factors has been observed in CRC pavements. These spalls are usually relatively shallow and of smaller area than the traffic-related spalling. Although specific causes have not been positively identified, they appear to be caused by stresses and strains induced by temperature and moisture changes and gradients. This type of distress has been observed in CRC pavements prior to opening to traffic, and in some instances spalling in lightly traveled lanes has been more severe than that in heavily traveled lanes in the same facility.

Historically, pumping of airport pavements has been a minor problem compared to highway pavements, possibly because of lower deflections and/or lower load repetitions. However, the increased flexibility of the CRC pavement system will result in increased deflections and thus increase the potential for pumping unless the foundation is adequately designed and constructed. Highway experience has shown that the use of

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well-stabilized subbases (bases) under CRC pavements has improved the performance of the overall system. Based upon this experience and the increased potential for pumping, cement or bituminous stabilized subbases (bases) are recommended for CRC pavements.

Environmental conditions during pavement construction, particularly during curing, may play an important role in the future performance of CRC pavements. The environmental conditions under which the pavement is cured are probably more important than in the jointed concrete pavements and may be a primary cause of nonload-associated distress such as areas with closely spaced cracks, spalling, and wide cracks. The temperature, moisture, and wind conditions at which a CRC pavement is placed and cured affect the crack pattern that develops. The ideal crack spacing is 5 to 8 ft.[7] As the crack spacing decreases, the stiffness of the pavement decreases and the rate of deterioration under traffic seems to increase. For larger crack spacings, cracks open wider and permit greater infiltration of moisture and incompressible material The possibility of steel corrosion is increased, and the magnitude of stress in the steel is increased. The initial crack pattern that develops is extremely important to the performance of CRC. One of the worst situations which can develop is closely spaced cracks as illustrated in Figure 12. Such locations are usually the first to experience distress.

At the present time little is known (especially quantitatively) about the part deflection plays in causing or sustaining the various other problems mentioned above and any attempt at designing CRC slabs to account for deflection would be only weakly based postulations or opinions that may or may not prove to be sound.

CRC OVERLAY PAVEMENTS

Inasmuch as the thickness of CRC pavement is being based upon limiting the load-induced stress, the empirically developed overlay design equations which base the thickness of overlay on the deficiency of thickness in the existing pavement as determined by a limiting stress model can be used. These equations have been used successfully for the design of jointed concrete pavements by the Portland Cement
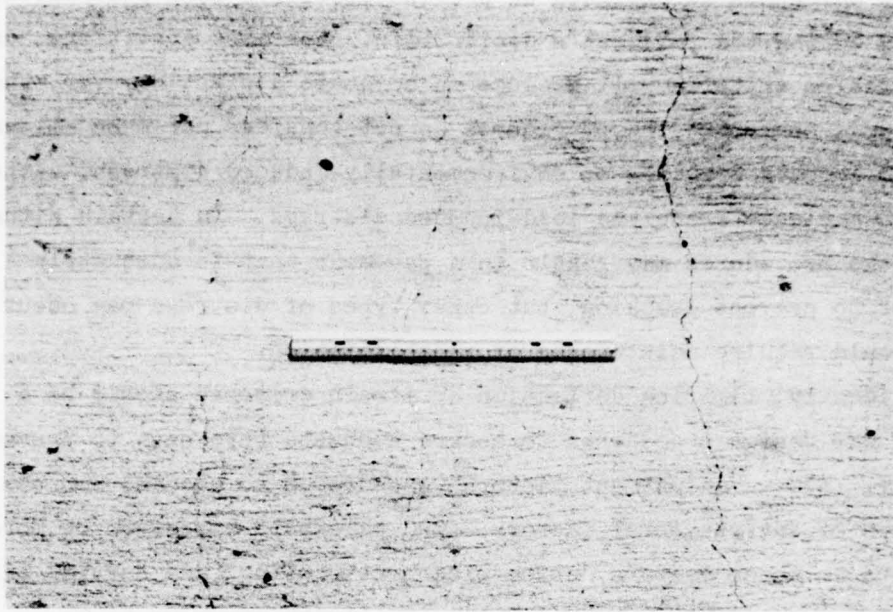
Figure 12. Example of closely spaced transverse
cracking pattern in CRC pavement

Association (PCA),[5] Corps of Engineers and Air Force,[8] and the FAA.[9]
In the overlay design procedure presented herein, these overlay design
equations have been coupled with the ARE-developed stress model and the
modified types of Corps of Engineers-developed performance criteria to
determine the thickness deficiency and required overlay thickness.

LIMITATIONS OF THESE PROCEDURES

In the discussion of the behavior of CRC pavements, the following
major distress manifestations have been identified:

a. Load-induced cracking.

b. Load-induced spalling.

c. Environmentally induced distress, such as abnormal crack
   patterns, spalling, etc., which may lead to premature
   failure of the pavement.

Of these three, load-induced cracking is the mechanism upon which
the design procedures presented in this report are based; i.e., the

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pavement thickness is designed to prevent excessive load-associated cracking during the pavement's design life. For most conditions, use of the design criteria will produce an adequate design; however, the user should note that the procedures do not consider nor make allowances for load-induced spalling or environmentally-induced distress, either of which may accelerate the load-induced distress. In certain situations use of the procedures may result in a pavement that is adequately designed to prevent cracking, but other types of distress may occur which would require maintenance or rehabilitation.

Ideally, limiting deflection or strain criteria should be a part of the design procedures to assure adequate thickness to prevent spalling. Also, "adjustment factors" are needed to account for the influence of environmental factors. CRC pavements appear to be more sensitive to these factors during placement, curing, and service life than jointed pavement systems. This sensitivity may have to be accounted for by application of factors to adjust the design requirements to local conditions, adjustment of input parameters for certain design conditions, or development of special construction specifications that are dependent on the geographic location and conditions during construction.

Both limiting deflection criteria and environmental "adjustment factors" will be extremely difficult to develop. However, the use of CRC should not be postponed until all the answers are available, because many of the problems can only be solved through experience. The use of the procedures as presented will, in the majority of cases, produce an adequate design. In the situation where premature distress that requires maintenance occurs, the types of distress that are likely to occur will not result in catastrophic failures. Although the designer should be aware of these facts, he should also realize that the probability of designing a functionally adequate pavement is quite good.

DESIGN PROCEDURES AND EXAMPLES - CIVIL AIRPORTS

SLAB-ON-GRADE

DESIGN PROCEDURE

Figure 13 shows in flowchart form the basic steps of the design procedure.

Site investigation. The site investigation should be accomplished in accordance with applicable parts of FAA Advisory Circular 150/5320-6B.[9] Existing information such as laboratory reports, design reports, and plans for other pavements at the location should be used to the fullest extent possible. Advisory Circular 150/5320-6B also gives procedures for use when conditions are such that either poor drainage or frost penetration and action are probable for the subgrade at the design site. An example of data derived from a site investigation is shown in Table 1.

Design parameters.

a. Material properties. The material properties required for use in this design procedure include the properties of the concrete, subbase material, subgrade, and reinforcement. The quality of materials and concrete mixes, control tests, methods of construction, and quality of workmanship are governed by the FAA Standards for Specifying Construction of Airports, Advisory Circular 150/5370-10.[10] Also, the design concrete flexural strength shall be determined in accordance with Advisory Circular 150/5370-10.[10] The tensile strength of the concrete may be estimated as:[11]

$$f_t \simeq \frac{R - 210.5}{1.02} \qquad (3)$$

where

f_t = tensile strength of concrete at 7 days, psi

R = flexural strength of concrete

The concrete modulus of elasticity in flexure is assumed to be 4×10^6 psi, unless the designer has reason to expect that the modulus will be significantly different. In the latter case the modulus shall be determined from the flexural test as specified in test method CRD-C 21-58.[12] The design

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┌─────────────────────────────────┐
│  Site Investigation             │
│    1.  Soil Sampling            │
│    2.  Laboratory Testing on Soils │
│    3.  Soil Classification      │
│    4.  Plate Load Tests         │
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┌─────────────────────────────────┐
│  Composite Support Design       │
│    1.  Treated Subgrade Consideration │
│    2.  k-Value on Natural Subgrade │
│    3.  Subbase Design           │
│    4.  Selection of Composite Design │
│        k-Value                  │
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┌─────────────────────────────────┐
│  Thickness Design Analysis      │
│    1.  Aircraft Traffic Considerations │
│    2.  Prediction of Allowable Stresses │
│    3.  Thickness Design Curves  │
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│  Special Provisions             │
│    1.  Terminal Treatment Design │
│    2.  Reinforcement Design     │
│    3.  Construction Joints      │
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        │  Final Design │
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        │ Construction │
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Figure 13. Procedure for CRC pavement design[1]

Table 1

Example of Properties of a Natural Subgrade
Obtained from a Site Investigation

	Station Along Runway						
	245	238	194	178	171	164	156
Liquid Limit	39.9	37.0	30.0	29.5	30.5	35.0	30.5
Plastic Limit	18.5	20.1	19.0	18.5	18.5	20.5	18.0
P.I.	20.5	16.9	11.0	11.0	12.0	14.5	12.5
Soil Class	CL	CL	CL	CL	CL	CL	CL
Density*	110.9	106.3	112.0	113.1	113.4	109.7	110.8
Moisture**	19.7	21.3	17.0	16.8	16.1	20.2	17.9
Subgrade Modulus†	90	75	115	120	180	90	105

* Pounds per cubic foot, dry.
** Percent.
† Pounds per square inch/inch.

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value of modulus of elasticity shall then be the mean value of the available test results. The allowable stress in the reinforcement steel shall be based on the relation[1]

$$f_s = 0.75f_y \qquad (4)$$

where

f_s = allowable working stress in steel

f_y = yield strength of the steel

The modulus of elasticity in flexure for stabilized subbase materials shall be chosen from a number of moduli as determined from the test method published as Appendix H of FAA Report RD-74-199[13] for cement-stabilized soil and Appendix B of FAA Report RD-73-198-II[14] for bituminous-stabilized soils. Asphalt stabilized materials are quite sensitive to temperature; therefore, the test temperature for these materials must be closely controlled at or near the expected average in-place temperature of the stabilized layer. If no estimate of the temperature is available, a test temperature of 77° F (20° C) is suggested. The modulus of soil reaction, k , shall be determined for the natural subgrade in accordance with MIL STD 621A, Method 104.[15]

<u>b</u>. <u>Aircraft traffic.</u> Aircraft traffic considerations account for the number, type, and load characteristics of the aircraft traffic for which the pavement is to be designed. The methods to be used for this are given in FAA AC 150/5320-6B.[9]

<u>c</u>. <u>Allowable stress.</u> The concept of "allowable stress" should also be considered as a design parameter for this design procedure. Here, "allowable stress" denotes the maximum stress that can be tolerated by concrete with a given flexural strength without excessive cracking when that stress is applied a certain number of times. In other words, theoretically it will take a certain number of applications of the allowable stress at a point in the slab to cause excessive load-induced cracking of the concrete having a given flexural strength. The nomographs in Figures 14-17 are presented as a means of determining the allowable stress for a given number of stress repetitions (design traffic) and for a design flexural strength. These nomographs are simply replots of the performance criteria shown in Figure 10, where the stress

ratio $\frac{R}{\sigma_i}$ is broken into components of flexural strength and

interior (allowable) stress. Thus, the relationship between the flexural strength of the PCC, the tensile stress in the
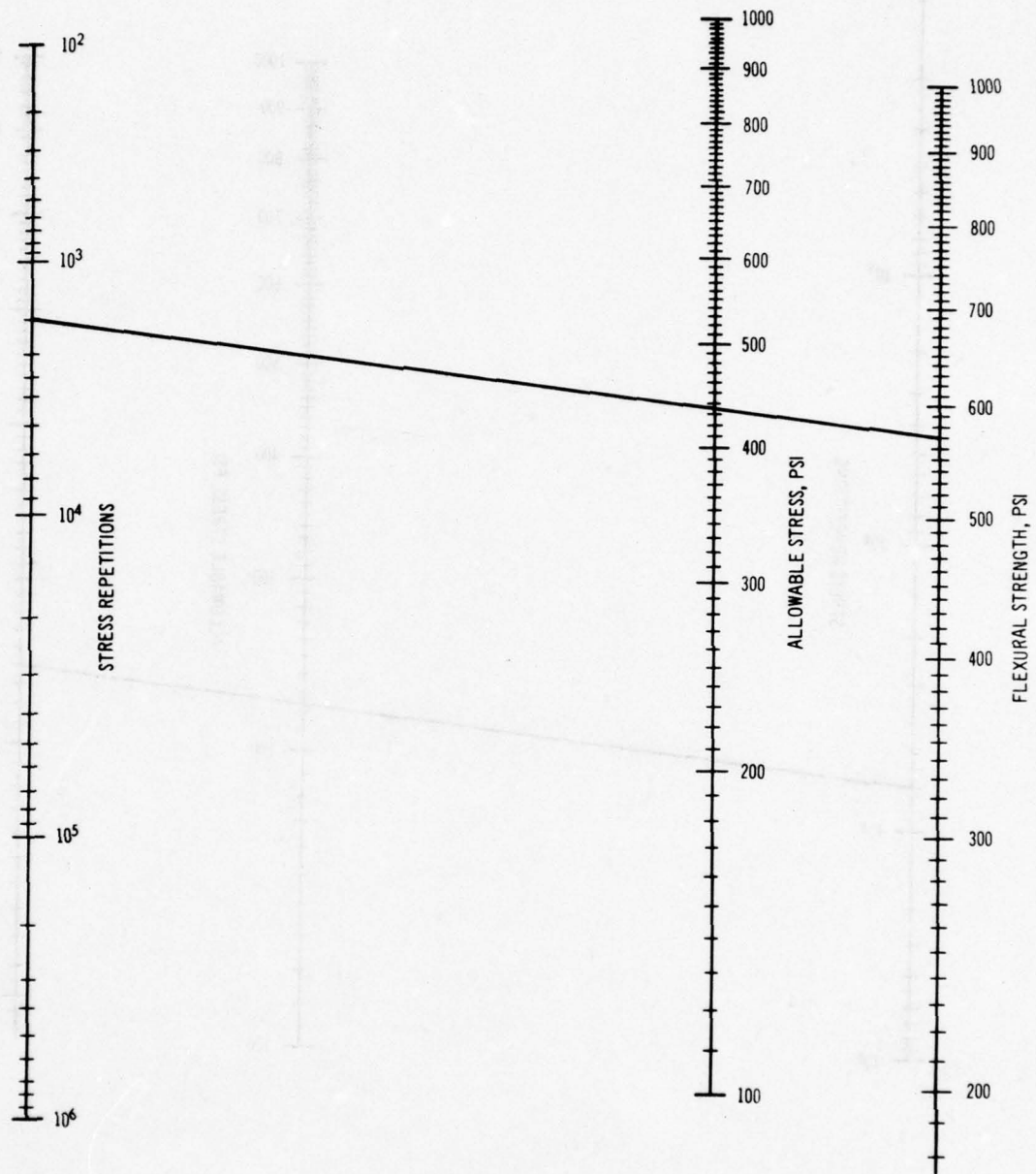
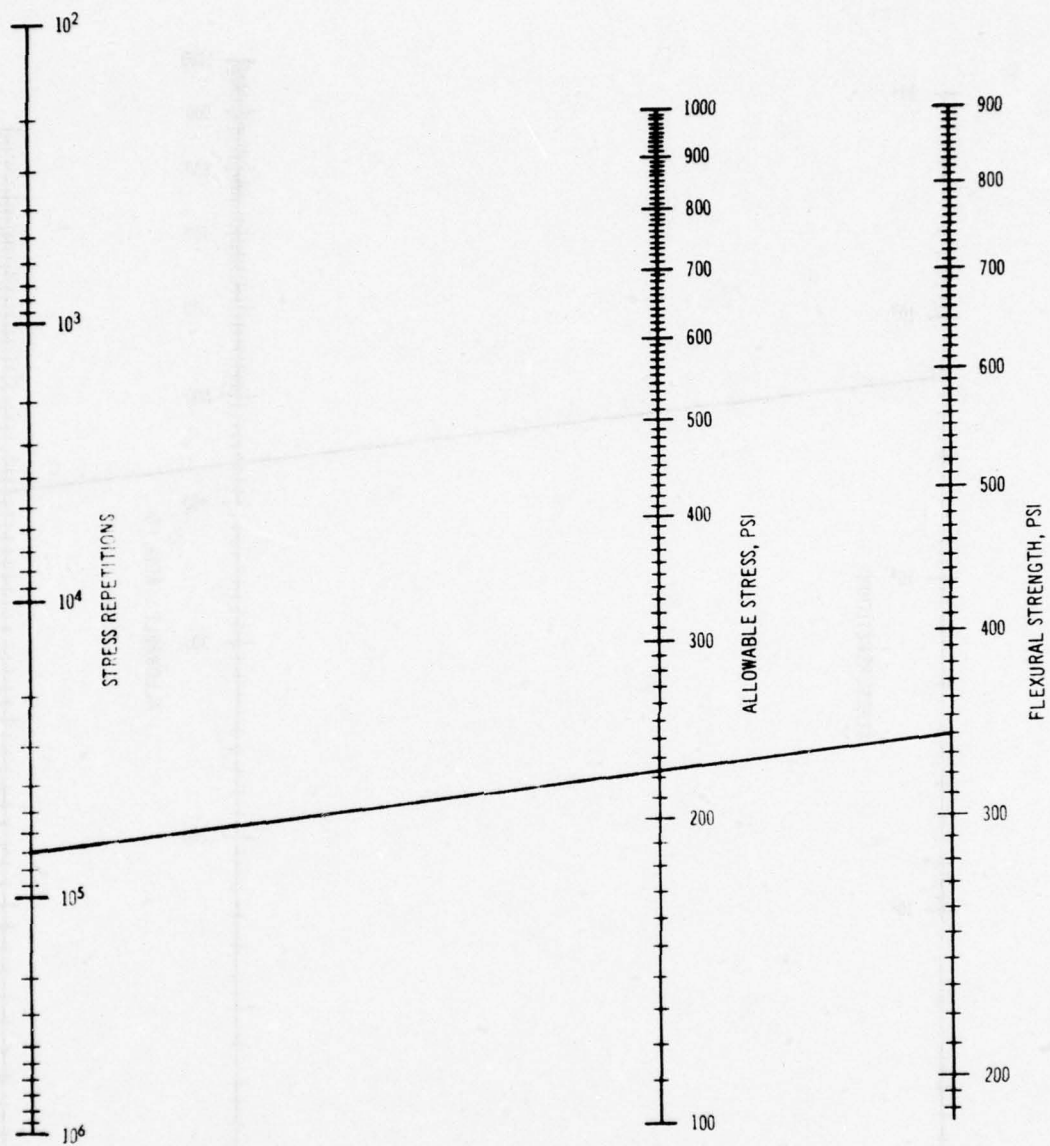Figure 14. Allowable stress nomograph
for k ≤ 200 psi/in.

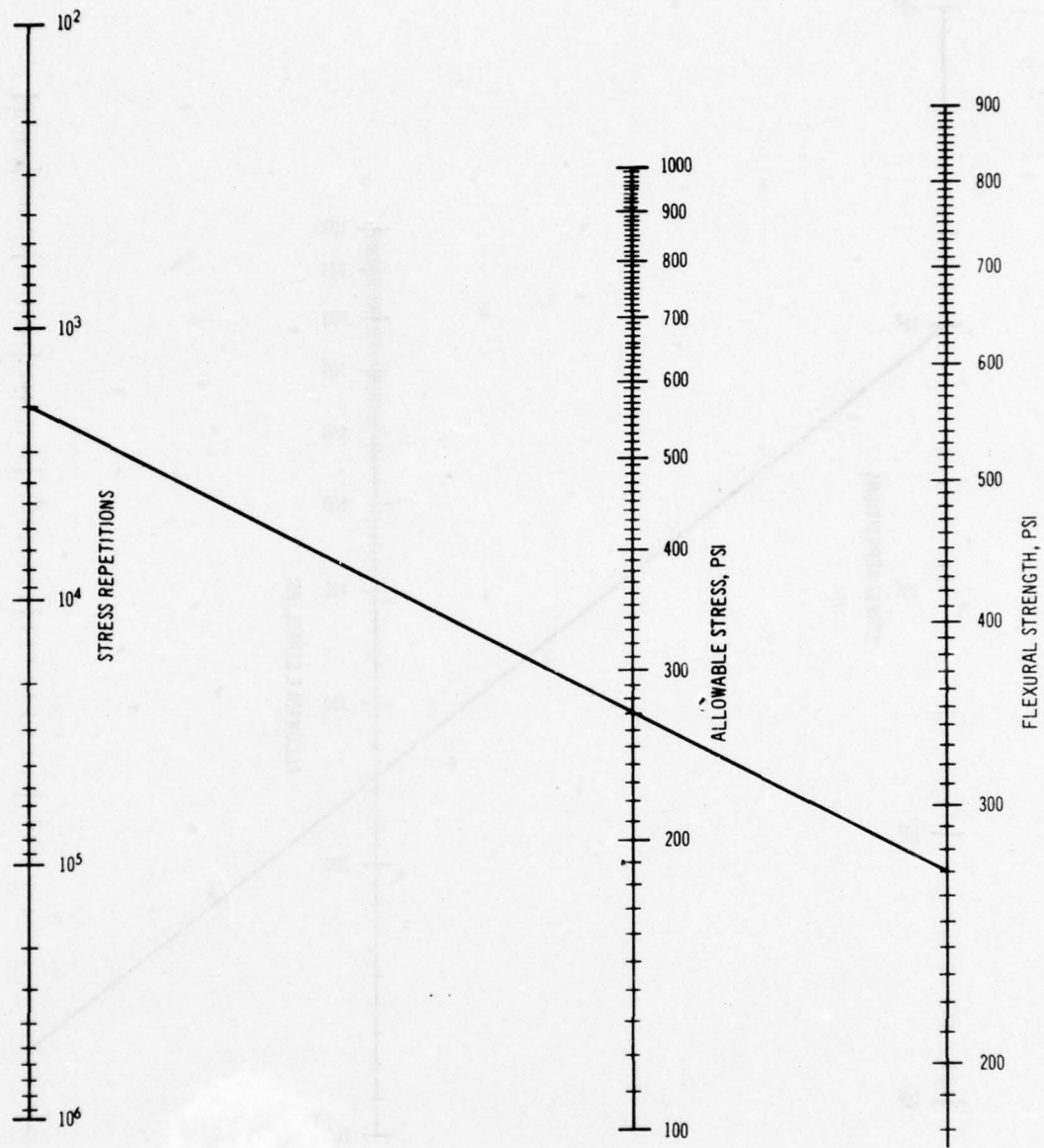Figure 15.   Allowable stress nomograph for   k = 300 psi/in.

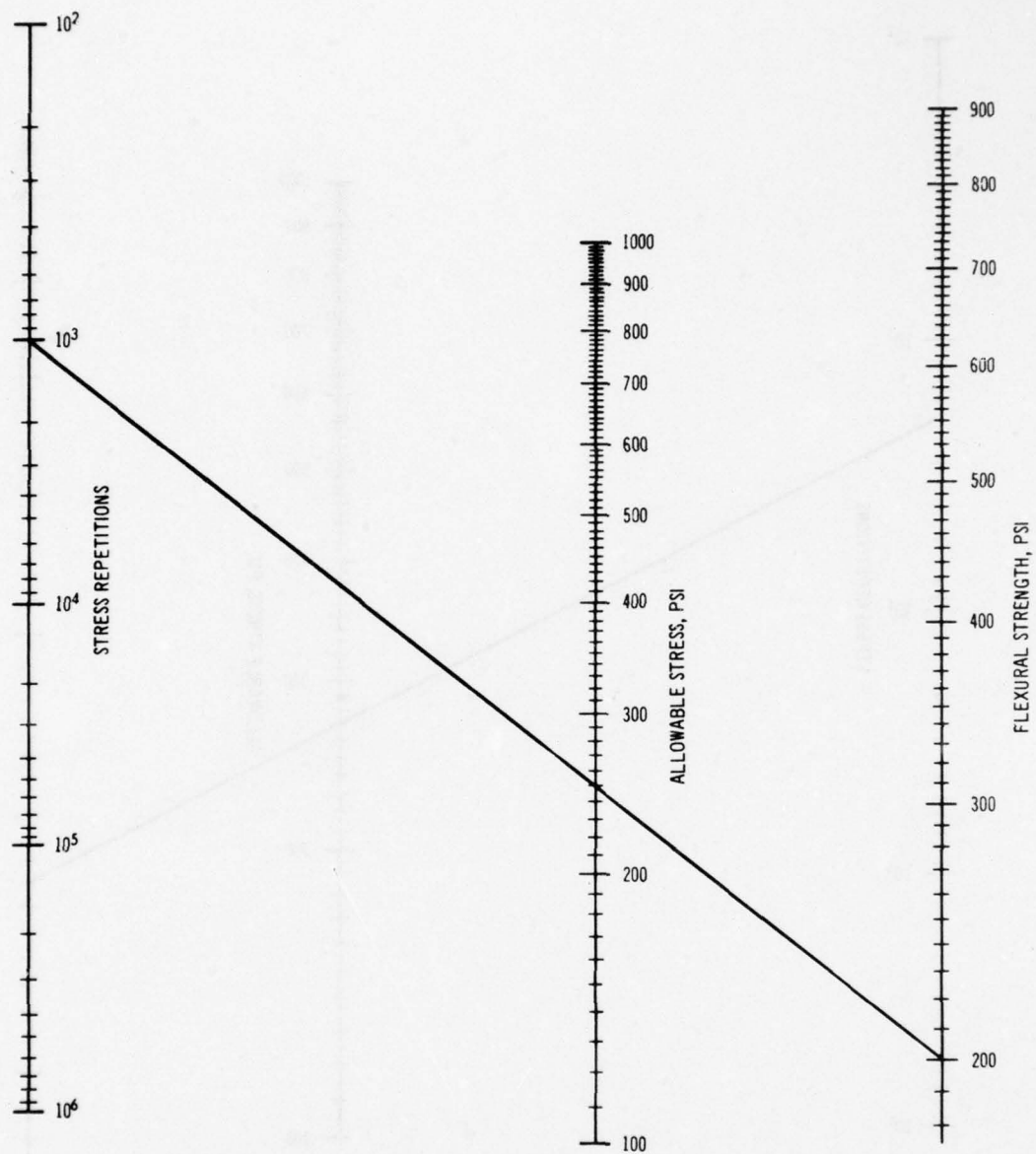Figure 16. Allowable stress nomograph for
k = 400 psi/in.

Figure 17. Allowable stress nomograph for
k = 500 psi/in.

slab, and the number of stress repetitions is shown by the three scales on the nomographs.

Subbase design and composite k-value. The site investigation and materials characterization shall furnish information necessary for subbase design analyses and for selection of composite design k-values for use in slab stress analyses. The final selection of a composite design k-value for slab stress analysis should include considerations of in-place subgrade treatments, subbase thickness, subbase material, and types of subbase stabilization.

a. Treatment of the subgrade. In addition to mechanical compaction of the natural subgrade, stabilization by chemical treatment may be warranted. The most common such chemical treatment is with lime; however, other stabilizing agents, such as cement and fly ash, exist which may be more advantageous in a given case. Chemical stabilization of the subgrade should be considered when the potential exists for detrimental frost effects (provided the stabilized material meets freeze-thaw requirements), for heave due to expansive soils, or for damage resulting from poor drainage conditions.

b. Subbase layers. Subbase layers for CRC airport pavements will be one of the following:

(1) Cement-stabilized material.

(2) Asphalt-stabilized material.

(3) Special materials depending on location and approval of the FAA.

For the pavement design analysis, either subbase type may be preselected for use in subsequent thickness designs or designs may be generated for alternate subbase types for economic or performance-potential comparisons. The subbase must be stabilized, and a minimum thickness of 4 in. is recommended for all new CRC pavements.

c. Composite design k-value. The composite design k-value is selected by entering the "Composite k-Value Chart," Figure 18, with the k-value that has been determined for the natural subgrade. From the k of the natural subgrade proceed vertically to the intersection of the line representing the thickness of chemically stabilized subgrade. From that intersection proceed horizontally to the subbase modulus of elasticity line. Next, drop a vertical line to the line representing the proposed thickness of the subbase. This point of intersection is then translated horizontally to the composite k-value scale. The point of intersection gives the composite k-value for the top of the subbase and

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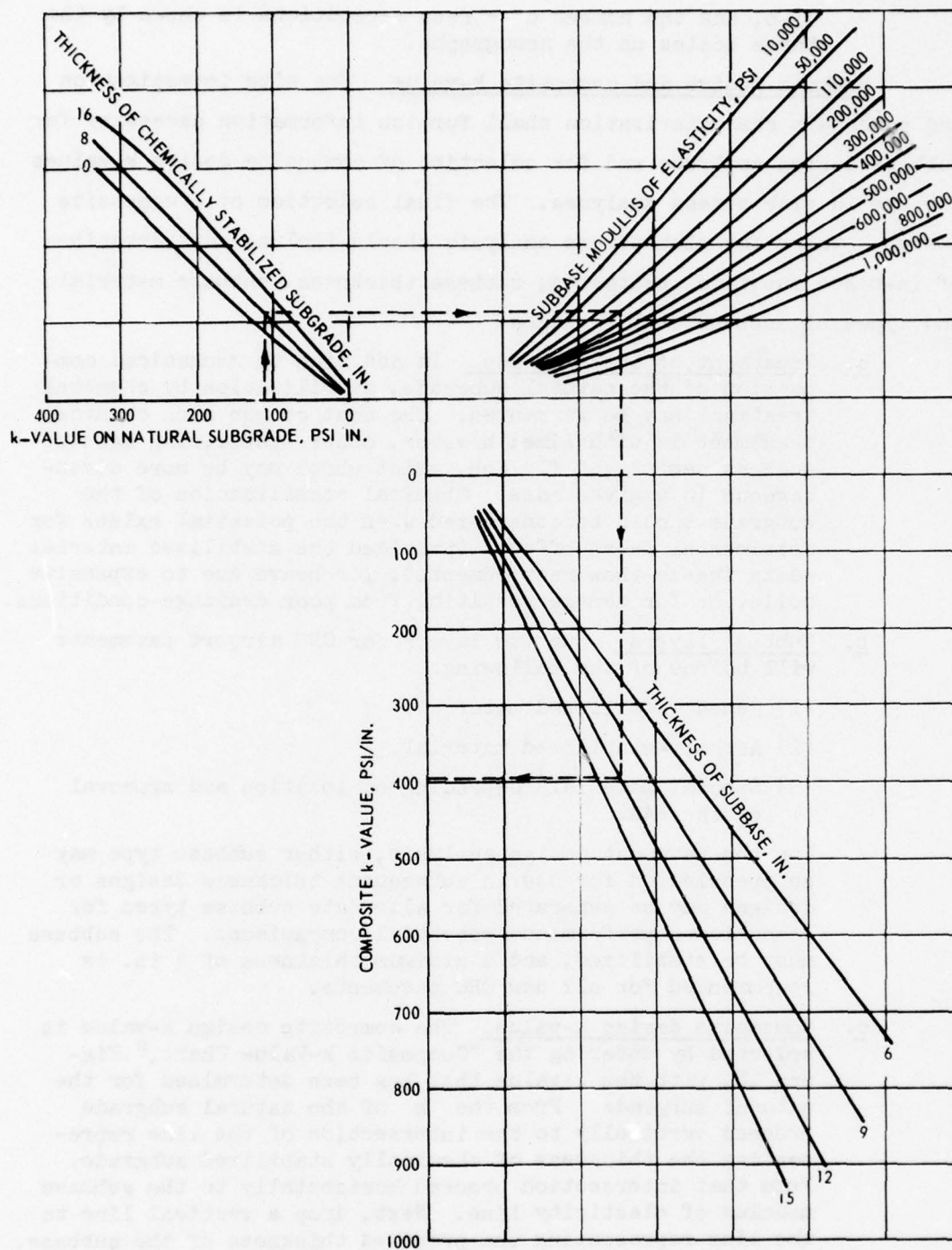
Figure 18. Composite k-value chart

is to be used in determining the allowable stress from Figures 14-17. The maximum composite k-value recommended for use is 500 psi/in.

Slab thickness design procedure.

<u>a</u>. There are three basic phases of the slab thickness design procedure:

  (1) Determination of design traffic (aircraft, departures, load, etc.).

  (2) Determination of allowable tensile stress in the concrete.

  (3) Selection of the required slab thickness.

  Because the allowable concrete stress determination is dependent on the subbase design, alternative subbase designs should be evaluated for any project.

<u>b</u>. <u>Design aircraft traffic.</u> Determination of the design aircraft traffic is very important, yet it is sometimes the most difficult phase of the design procedure. The design aircraft information should include all of the major aircraft which are expected to use the pavement during its design life. The design chart in this procedure is based on maximum gross weight (MGW) of the aircraft. The MGW of the aircraft used in constructing Figure 19 are contained in Table 2. This means that for design weights (DW) less than MGW the allowable stress that is obtained from Figure 14, 15, 16, or 17 must be multiplied by the ratio of the MGW to the DW $\left(\dfrac{MGW}{DW}\right)$, before entering the design chart in Figure 19. The procedure for relating all of the expected traffic to equivalent departures of a single design aircraft is given in FAA AC 150/5320-6B.[9] In order to utilize the stress analysis charts (Figures 14-17) the number of departures of the design aircraft must be converted to stress repetitions. To do this, divide the number of departures by the aircraft repetition factor, obtained from Table 3, for the design aircraft.

<u>c</u>. <u>Allowable stress.</u> The allowable stress in the pavement slab for the design traffic must be determined next.

  (1) The modulus of soil reaction, k , of the natural subgrade must be determined by plate bearing tests in accordance with Reference 15.

  (2) Similarly, the subbase modulus of elasticity must be determined in accordance with the test procedures contained in Reference 13 or 14.

  (3) After the subgrade k and the subbase modulus of elasticity have been obtained, the composite k (or effective k , on the top of the subbase) is obtained from Figure 18.

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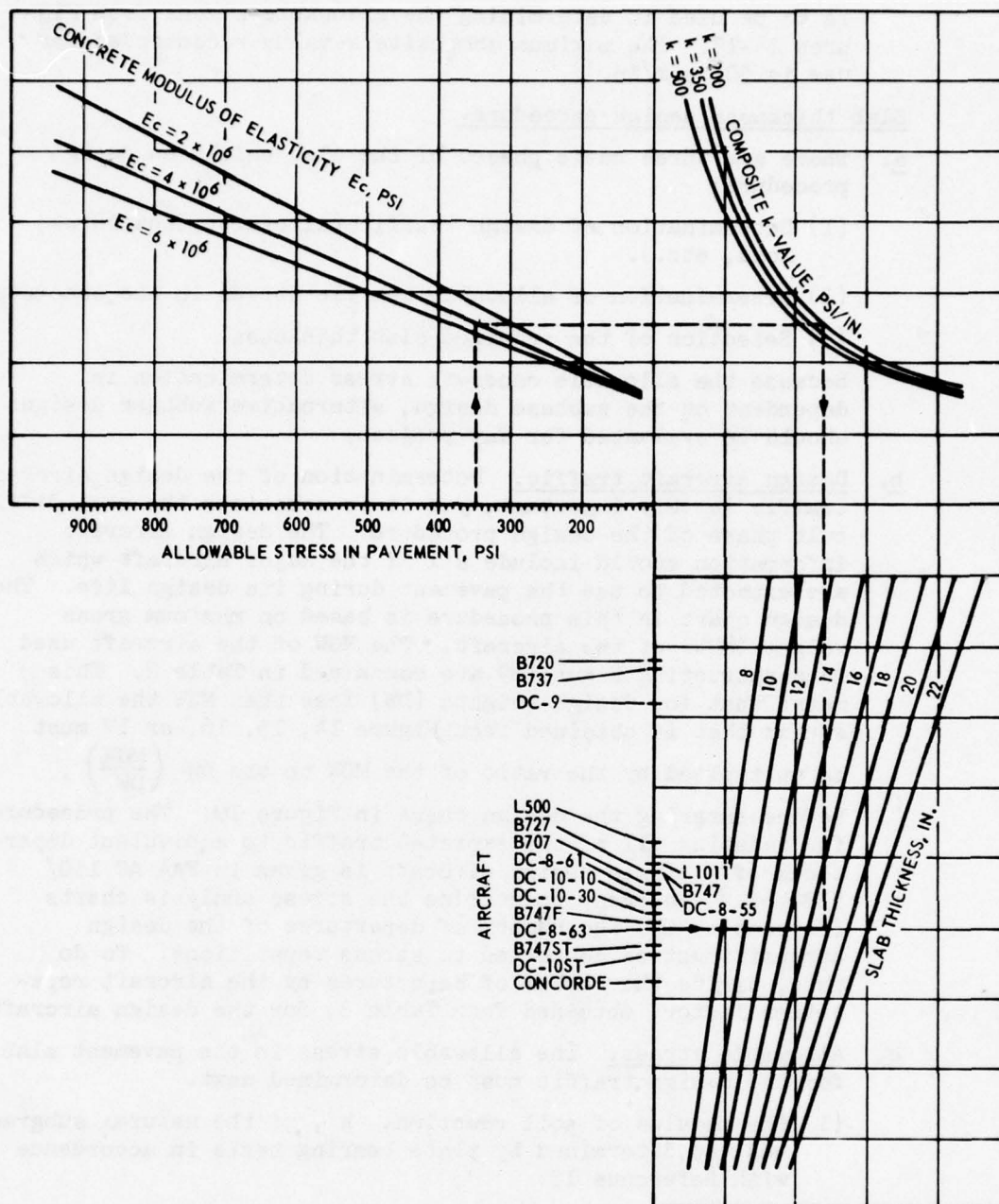
Figure 19. CRC pavement thickness design chart for civil airports[1]

Table 2

Aircraft Data - Civil Airports

Aircraft Designation	Maximum Gross Aircraft Weight, kips	Maximum Main Gear Tire Load, kips
B-737	109	25.8
DC-9	113	26.9
L-1011	428	50.8
B-727	168	39.9
B-747	765	45.4
B-707	331	39.3
DC-10-10	429	50.9
DC-10-30	558	52.6
DC-8-63	362	43.0
Concorde	383	45.5

Table 3

Aircraft Repetition Factors for Civil Aircraft

Aircraft	Critical Areas	Noncritical Areas
B-747	3.70	5.54
DC-10-10	3.64	5.80
DC-10-30	3.42	5.44
L-1011	3.62	5.82
DC-8-63	3.26	6.05
B-727	3.25	6.00
B-707	3.24	6.12
DC-9	3.58	6.90
B-737	3.67	7.32
Concorde	2.97	5.71

(4) Using the design concrete flexural strength and the design stress repetition level, enter the appropriate (depending on the composite k-value) stress analysis chart (Figures 14-17) to determine the allowable tensile stress in the concrete. Interpolation between the charts is possible for intermediate k-values.

d. **Slab thickness.** The slab thickness required to accommodate the design traffic is now determined from the design curve presented as Figure 19. As an example for reading the nomograph, suppose the allowable stress derived from Figure 14 (k = 200 psi/in.) is 350 psi, the concrete modulus of elasticity, E_c, is 4×10^6 psi, and the design aircraft is the DC-8-63. Then following the dashed arrows in Figure 19, the design CRC slab thickness is 17.5 in. See SPECIAL PROVISIONS for end anchorage, reinforcement, and joint design considerations.

DESIGN EXAMPLE AND COMPARISONS - NEW PAVEMENT

Example design problem. The following example illustrates the use of the design procedure just described. The example problem is to prepare a thickness design for a critical area pavement at a major hub airport. The subgrade soil characteristics (derived from the site investigation) are given in Table 1. The average k-value on the subgrade is found to be 110 psi/in. The characteristics of the concrete to be used are $E_c = 4 \times 10^6$ psi and R = 700 psi. The pavement is to be designed for 88,560 total departures (4428 annual) of the B-727-200. The design is to be based on MGW of the aircraft, and the corresponding wheel load is 39,900 lb. Other design features pertinent to the problem include: 8 in. of lime treatment for the subgrade; no problems of frost heave or settlement are expected; a cement-stabilized subbase with E_{SB} = 200,000 psi is to be used; and the thickness of the subbase is specified as 12 in.

a. **Design traffic.** From Table 3, the aircraft repetitions factor for the B-727-100 is 3.19. Thus, the total number of maximum stress repetitions occurring at any location is $\frac{88,560}{3.19}$ = 27,762 (use 2.8×10^4).

b. **Allowable stress in slab.** With the natural subgrade k-value, the thickness of treated subgrade, the subbase modulus of

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elasticity, and the thickness of the subbase, the composite k-value on the top of the subbase is found to be about 400 psi/in. from Figure 18. The next step in the design procedure is to enter Figure 16 with 2.8×10^4 stress repetitions and the design concrete flexural strength of 700 psi to determine the allowable concrete stress for the design traffic. The allowable stress determined is approximately 550 psi.

c. Design slab thickness. Finally, the CRC pavement thickness is determined from Figure 19. The concrete modulus of elasticity, E_c, is used with the allowable concrete stress, the composite k-value, and the design aircraft to determine the design pavement thickness. The figure gives a thickness of about 10.0 in.

Comparison with jointed nonreinforced concrete pavement design.

A thickness design based on the same parameters as the CRC example above has been determined by following the present FAA design procedure[9] for jointed nonreinforced pavement. The design B-727-200 traffic gives 4428 annual departures. Then the jointed nonreinforced pavement thickness required for a k-value of 400 psi/in. and R = 700 is about 13 in. The design thickness of the pavement slab that resulted from the CRC design procedure was 10.0 in. This represents a reduction in thickness from the conventional FAA jointed nonreinforced concrete pavement design of 13 - 10.0 = 3.0 in., or about 23 percent for this example.

OVERLAY DESIGN

DESIGN PROCEDURE

A flowchart showing the basic steps of the overall CRC overlay design procedure is presented as Figure 20. This procedure is considered applicable only to CRC overlays of existing rigid pavements. If the overlay is to be placed on an existing flexible pavement, plate bearing tests shall be used to determine the k-value on top of the flexible pavement. The determined k-value is then used as the composite k-value and the design procedure for new CRC pavement previously described shall be followed.

The proposed overlay design method is to use the existing thickness deficiency equation for a rigid overlay over a rigid base pavement

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┌─────────────────────────────────────────┐
│  Site Investigation                     │
│   1.  Testing In-Place Pavement         │
│   2.  Materials Sampling                │
│   3.  Condition Surveys                 │
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│  Evaluation of Materials                │
│   1.  Testing for Existing Materials    │
│   2.  Design Values for Existing Materials │
│   3.  Testing of New Materials          │
│   4.  Design Values for New Materials   │
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│  Thickness Design Analysis              │
│   1.  Thickness Design for              │
│       Equivalent Slab-on-Grade          │
│   2.  Thickness Design for Overlay      │
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│  Special Provisions                     │
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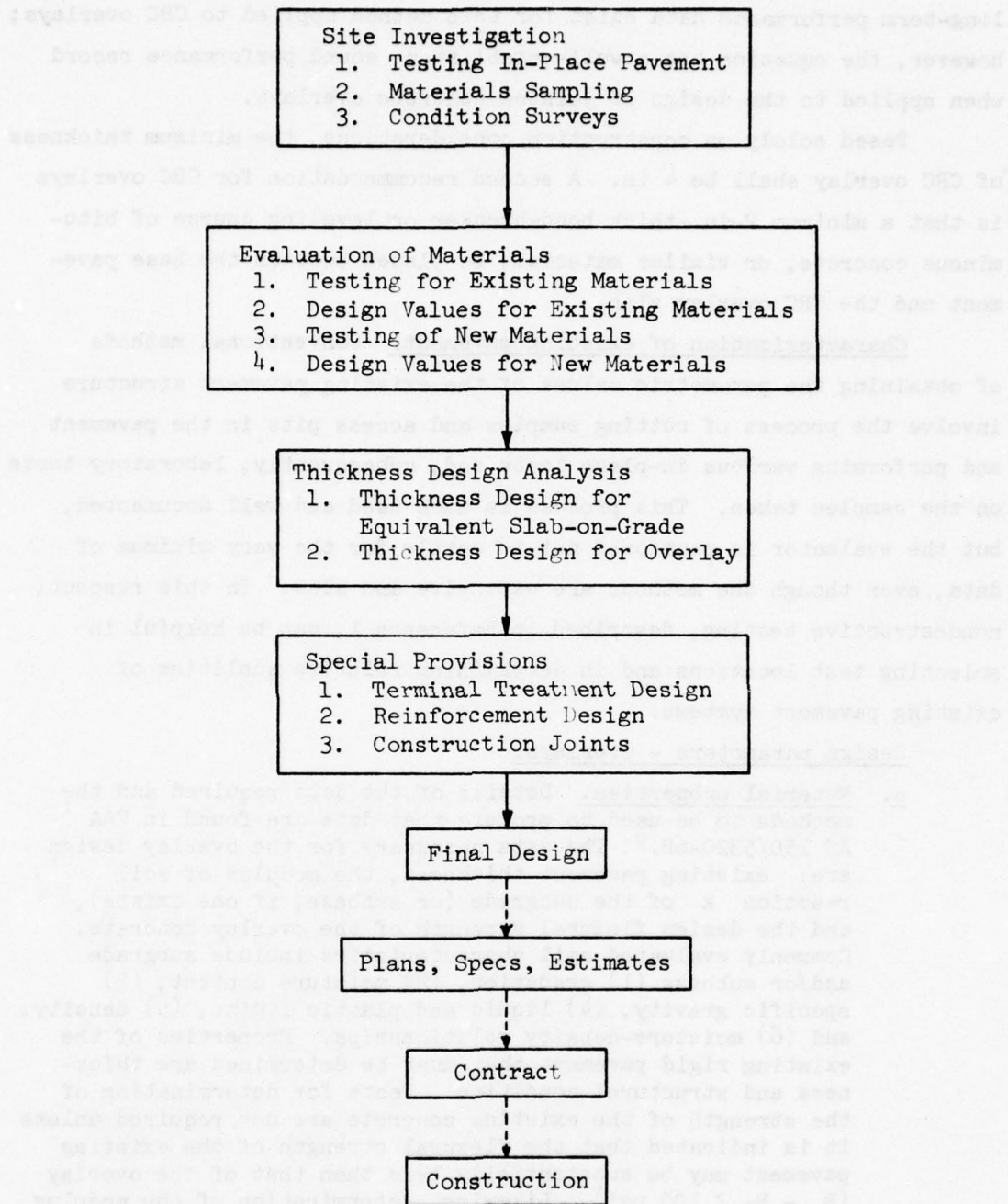
Figure 20. Procedure for CRC overlay pavement design

with an asphalt concrete bond-breaker course between the two slabs. No long-term performance data exist for this method applied to CRC overlays; however, the equation has a well-established, sound performance record when applied to the design of jointed concrete overlays.

Based solely on construction considerations, the minimum thickness of CRC overlay shall be 4 in. A second recommendation for CRC overlays is that a minimum 2-in.-thick bond-breaker or leveling course of bituminous concrete, or similar material, be placed between the base pavement and the CRC overlay slab.

Characterization of existing pavement. Conventional methods of obtaining the parametric values of the existing pavement structure involve the process of cutting samples and access pits in the pavement and performing various in-place tests and, subsequently, laboratory tests on the samples taken. This process is much used and well documented, but the evaluator is cautioned not to settle for the very minimum of data, even though the methods are expensive and slow. In this respect, nondestructive testing, described in Reference 1, can be helpful in selecting test locations and in determining relative qualities of existing pavement systems.

Design parameters - overlays.

a. Material properties. Details of the data required and the methods to be used to procure that data are found in FAA AC 150/5320-6B.[9] The data necessary for the overlay design are: existing pavement thickness, the modulus of soil reaction k of the subgrade (or subbase, if one exists), and the design flexural strength of the overlay concrete. Commonly evaluated soil characteristics include subgrade and/or subbase (1) gradation, (2) moisture content, (3) specific gravity, (4) liquid and plastic limits, (5) density, and (6) moisture-density relationships. Properties of the existing rigid pavement that must be determined are thickness and structural condition. Tests for determination of the strength of the existing concrete are not required unless it is indicated that the flexural strength of the existing pavement may be substantially less than that of the overlay $(R_o - R_e \geq 100 \text{ psi})$. Likewise, determination of the modulus of elasticity of the concrete in the base pavement is not necessary unless it is suspected that $|E_e - E_o| > 1,000,000 \text{ psi}$.

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b. <u>Aircraft traffic and pavement performance criteria.</u> These factors are considered in the same manner for CRC overlays as they are for new pavement design.

<u>Design procedure.</u>

a. <u>Input parameters.</u> The design of a concrete overlay on a rigid pavement requires an assessment of the structural integrity of the existing rigid pavement, and thus, the support which the existing pavement will provide for the overlay. The condition factor must be assigned after a pavement condition survey. The selection of a condition factor is a judgment decision which is somewhat arbitrary. No method of determining structural integrity by quantitative measurement exists; thus, until such a method is developed the assessment of the condition factor will remain a judgment decision. In order to provide some guidance for assessment of the condition factor so that more uniformity can be attained, the following values, discussed in more detail in Reference 9, are offered for guidance:

C = 1.0 for existing pavement in good condition--some minor cracking, but no structural defects.

C = 0.75 for existing pavement containing initial corner cracks due to loading, but no progressive cracking or joint faulting.

C = 0.35 for existing pavement in poor structural condition--badly cracked or crushed and faulted joints.

Also necessary for use of this design method are the thickness of the existing jointed concrete pavement, h_e , the thickness of CRC pavement equivalent to the thickness of existing jointed pavement, h_e' , and the thickness of a single-slab CRC pavement, h , that would be required over the existing subgrade (or subbase, if one exists) for the design conditions. The thickness of the existing jointed concrete pavement can be measured directly in test pits or on extracted cores. The single-slab thickness must be determined according to the design procedure for new CRC pavement previously described. The thickness of CRC pavement which is equivalent to the existing thickness of jointed concrete pavement is determined by finding the life of the existing pavement, in terms of stress repetitions, for the design load. The equivalent CRC pavement thickness, required for this repetition level and design load, is then determined according to the design procedure for new CRC previously described.

b. <u>Design equation.</u> The equation recommended for design of CRC overlays is:

$$h_o = \sqrt{h^2 - Ch_e'^2} \qquad (5)$$

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where

h_o = required CRC overlay thickness

h = required CRC single-slab thickness

C = condition factor for existing pavement

h_e' = thickness of CRC pavement equivalent to the existing jointed concrete thickness

c. <u>Design procedure.</u> After the condition survey and the existing pavement characterization, the value for C is chosen and h_e' and h determined. The first step in determining the thickness of CRC equivalent to the existing jointed concrete pavement is to determine the design life of the existing pavement by using a design curve as shown in Figures 21-26. The curves are entered with existing jointed concrete pavement thickness, design load, k-value, and flexural strength. The design life (in terms of annual departures) may be interpolated at the point of intersection of a vertical line through the existing slab thickness and a horizontal line obtained by starting with the flexural strength and proceeding through the chart as illustrated by the dashed lines in Figures 21-26. The total number of allowable departures which the existing pavement would have withstood when new may then be obtained by multiplying the annual departures by 20. Total departures may be converted to total stress repetitions by dividing departures by the appropriate stress repetition factor from Table 3. The next step is to determine h_e' with the procedures described previously for new CRC. The required value of h is also determined with this procedure. Any steel in the base pavement should be neglected in the design of the overlay. Finally, the design value for h_o is determined from Equation 5 above. Should the case arise where an existing CRC pavement is to be overlaid, the existing thickness of the CRC is used directly in Equation 5.

d. The occasion may arise when h is less than Ch_e' in which case the minimum thickness of 4 in. of CRC overlay will be used. See SPECIAL PROVISIONS for CRC reinforcement design, joints, etc.

DESIGN EXAMPLES AND
COMPARISONS - OVERLAYS

<u>Example design problem.</u> A thickness design is desired for a CRC overlay of a critical area pavement at a major airport. The design traffic consists of 88,560 departures of the B-727-200. The direct sampling evaluation and the condition survey produce the information about the subgrade as is shown in Table 1. The average k value is found to be
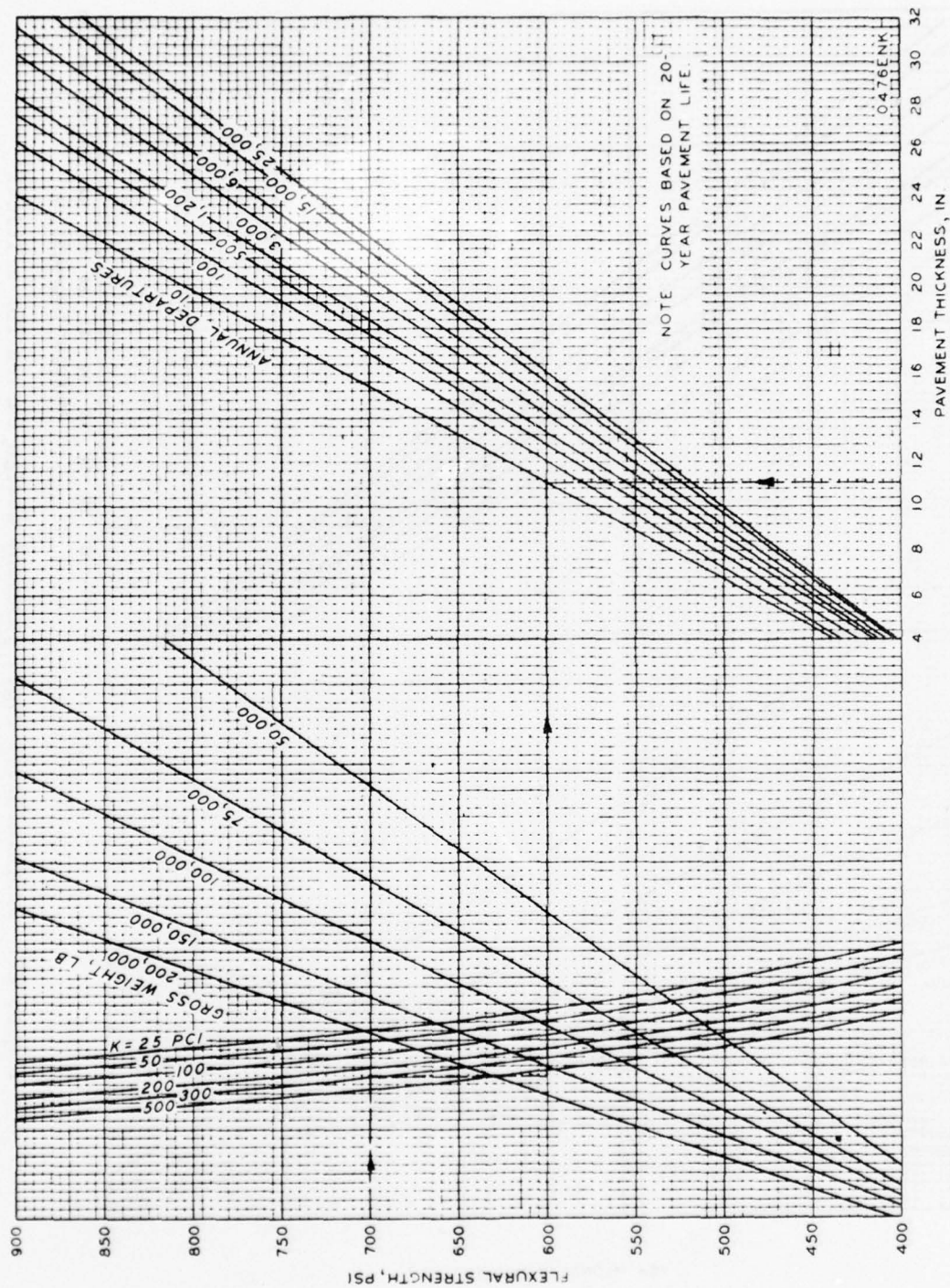
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Figure 21. Nonreinforced rigid pavement design curves for critical areas, DC-9, B-737, and B-727 aircraft

Figure 22. Nonreinforced rigid pavement design curves for critical areas, DC-8-63 and B-707 aircraft

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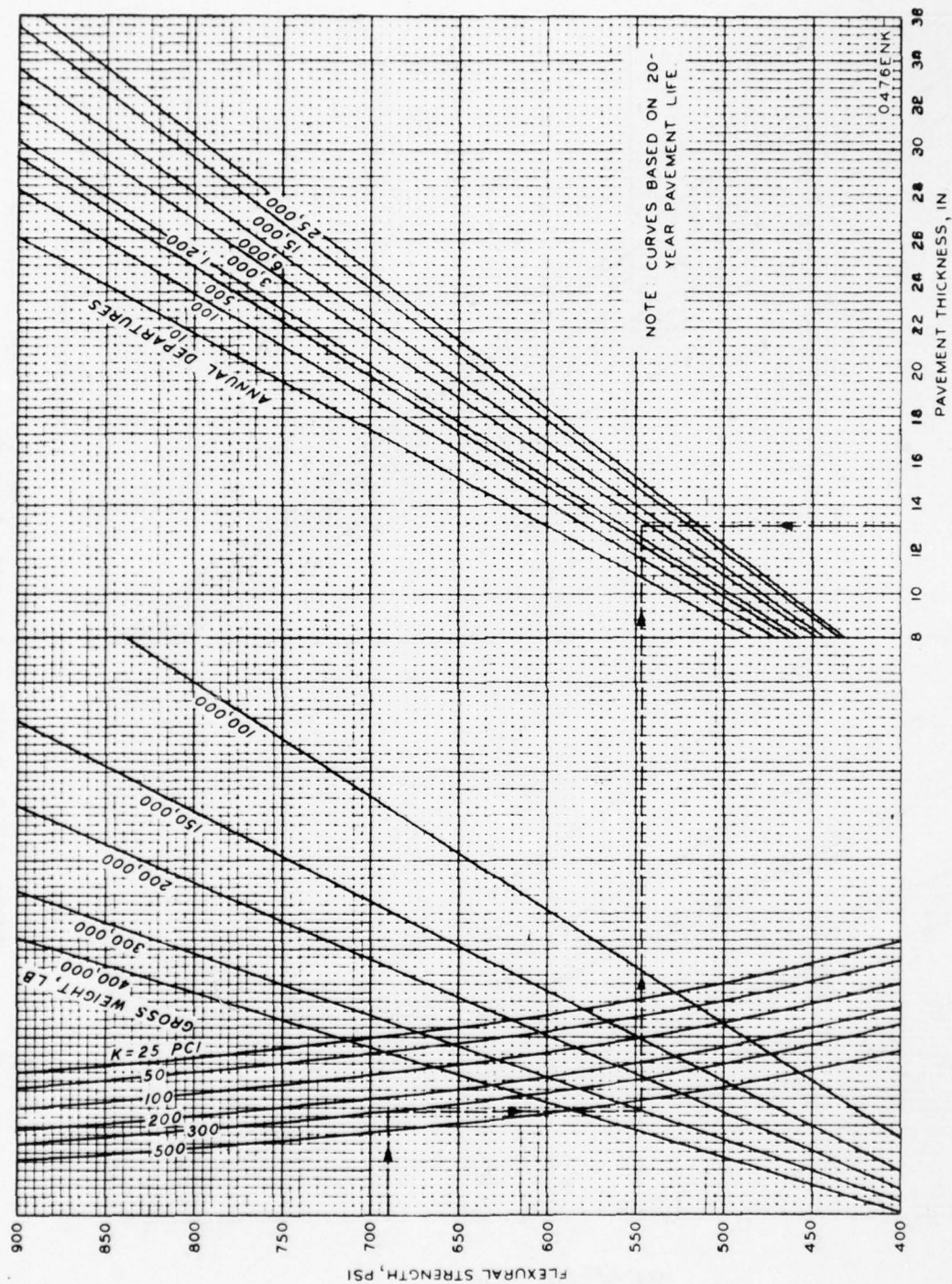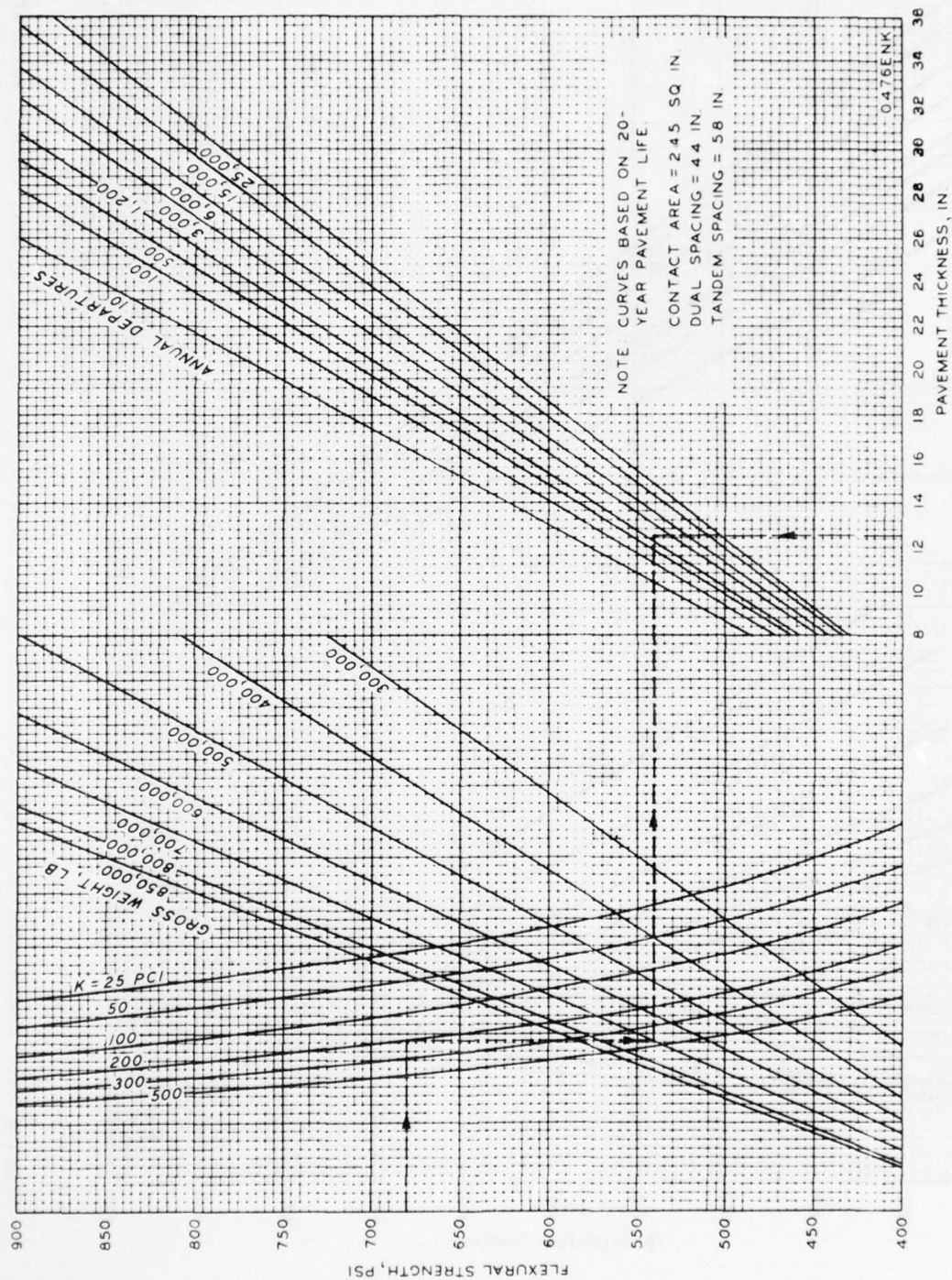
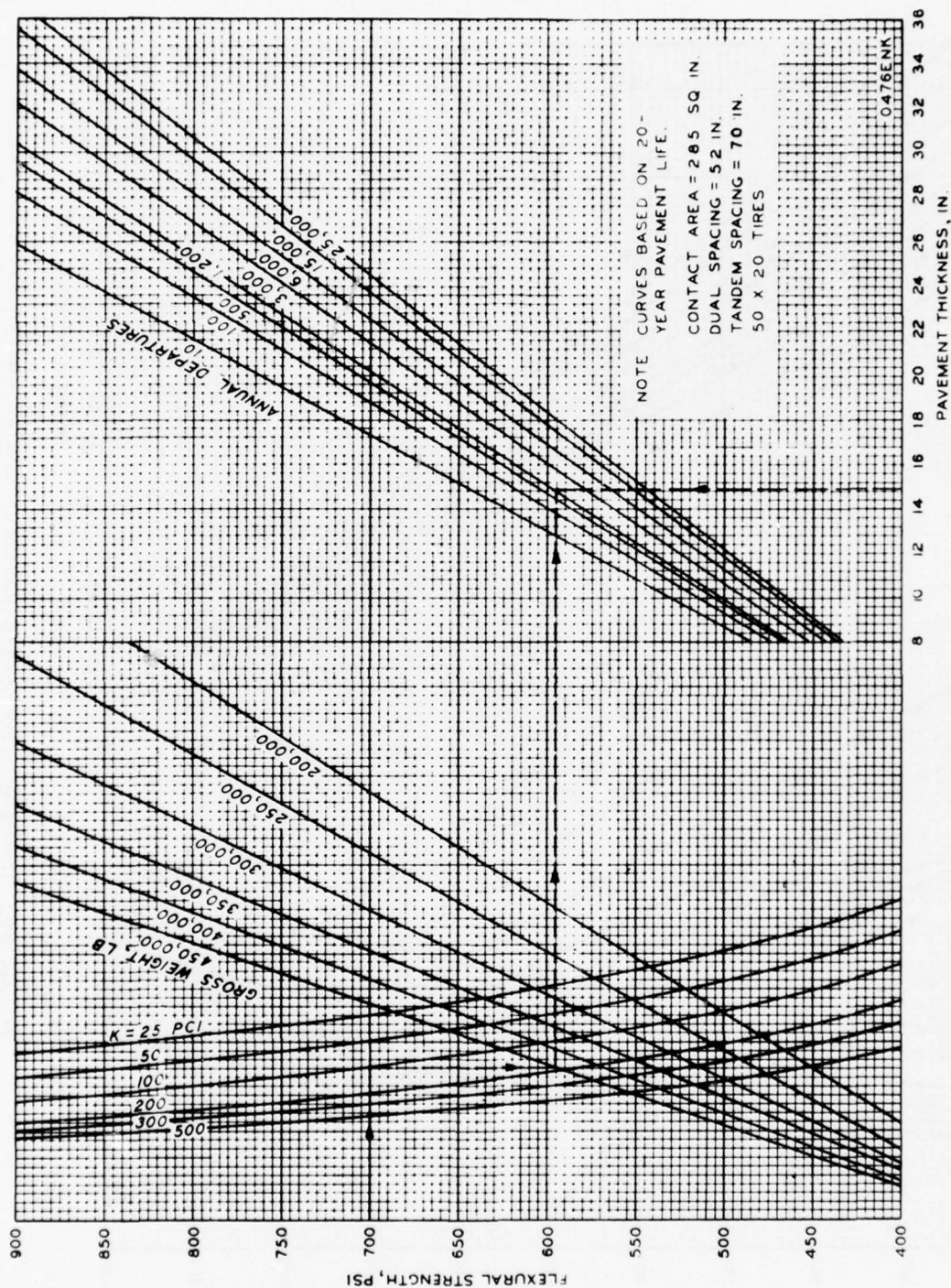Figure 23. Nonreinforced rigid pavement design curves for critical areas, B-747 aircraft

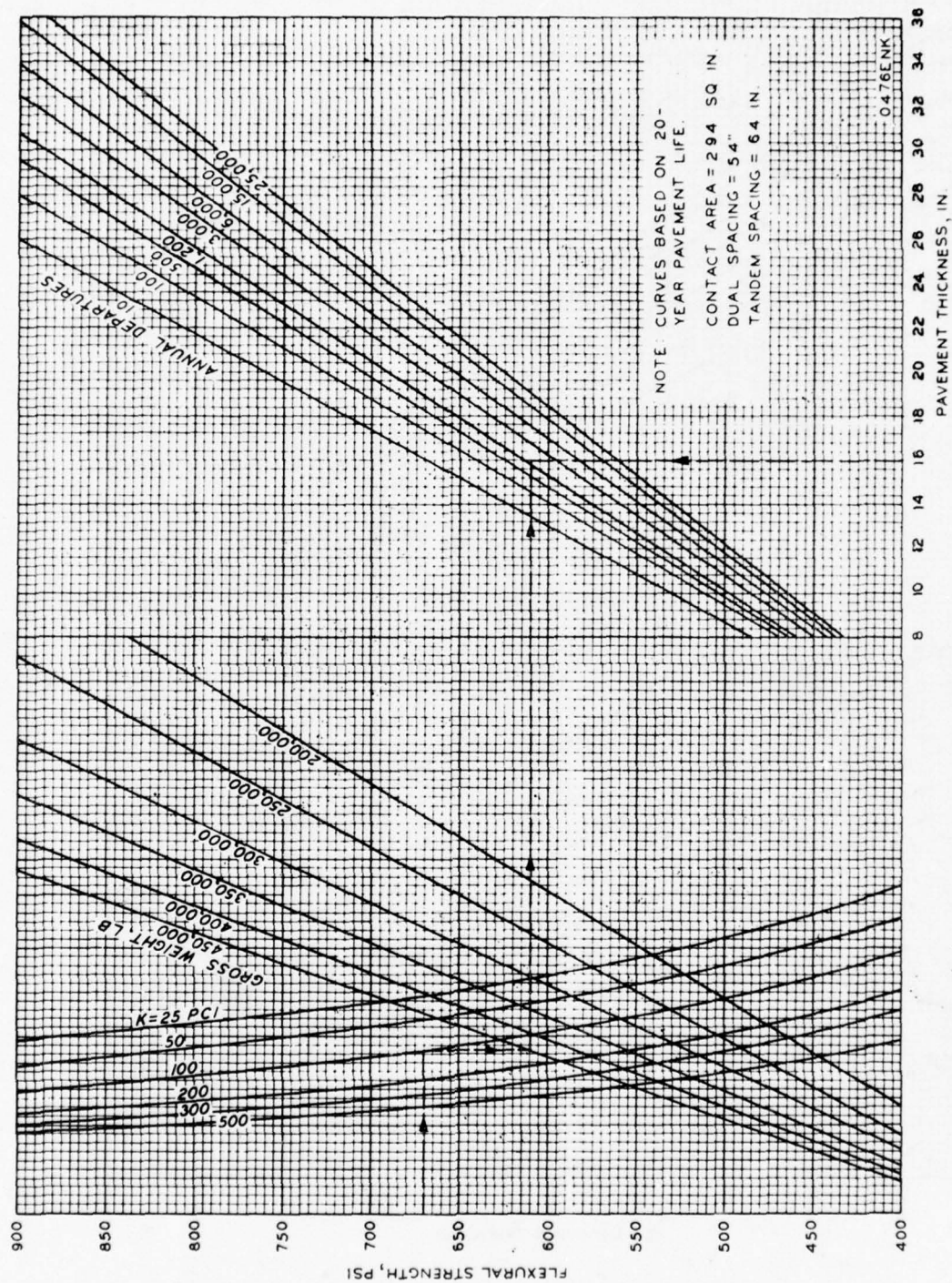Figure 24. Nonreinforced rigid pavement design curves for critical areas, L-1011 aircraft

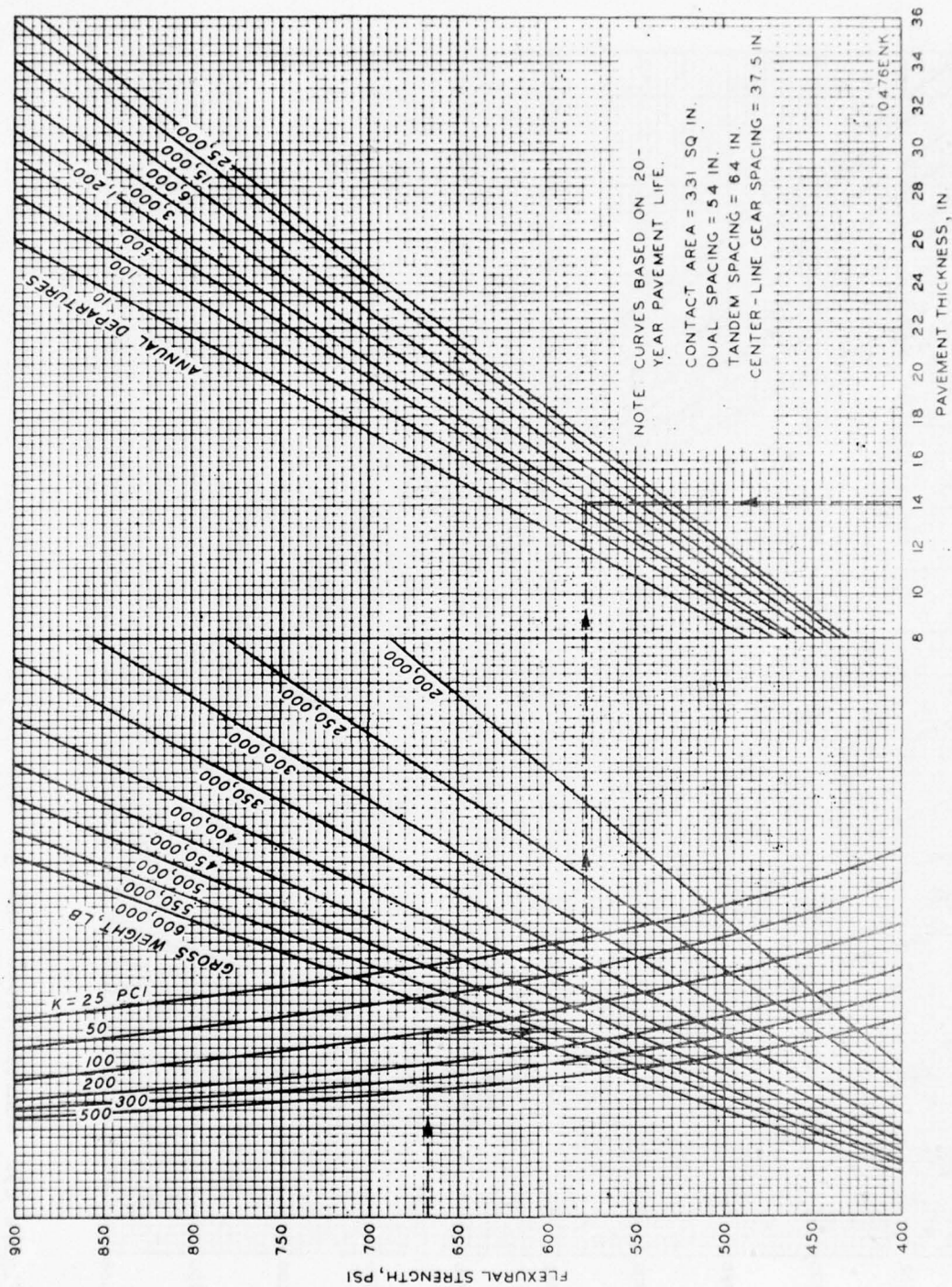Figure 25. Nonreinforced rigid pavement design curves for critical areas, DC-10-10 aircraft

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Figure 26. Nonreinforced rigid pavement design curves for critical areas, DC-10-30 aircraft

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110 psi/in. and the characteristics of the concrete to be used for the overlay are $E_e = 4 \times 10^6$ psi and $R = 700$ psi. (Assume no significant difference in flexural strength and modulus of elasticity between existing and overlay slabs.) The pertinent characteristics of the existing pavement are: (a) 8-in. unstabilized granular subbase, $k = 300$ psi/in., and (b) 11-in. jointed nonreinforced concrete pavement with $C = 0.75$.

    a. <u>Required CRC single-slab thickness.</u> Since the k-value on the subbase is 300 psi/in., Figure 15 is entered directly to determine the allowable concrete stress for 2.8×10^4 stress repetitions and $R = 700$ psi. The allowable stress is found to be 505 psi. Next, enter Figure 19 and find that the required thickness is 11.8 in.

    b. <u>Calculation of CRC thickness equivalent to existing jointed slab thickness.</u> The thickness of CRC pavement that is equivalent to the existing 11-in.-thick jointed concrete pavement is determined as follows:

        (1) Figure 21 is entered with a thickness of 11 in., a flexural strength of 700 psi, a k-value of 300 psi/in. and an aircraft weight of 168,000 lb, and an allowable annual departure level of 10 is determined.

        (2) The 10 annual departures are converted to 200 total departures by multiplying by 20, and the total departures are converted to 61 stress repetitions by a repetition factor of 3.25 obtained from Table 3.

        (3) The allowable stress in the equivalent CRC pavement is found by entering Figure 15 with a flexural strength of 700 psi and 61 stress repetitions. An allowable stress of 700 psi is obtained.

        (4) Finally, the CRC equivalent thickness of 9.0 in. is obtained from Figure 19.

    c. <u>Calculation of overlay thickness.</u> Use $h = 11.8$ in., $C = 0.75$, and $h_e' = 9.0$ in. in Equation 5. The calculated overlay thickness, h_o , is 8.9 in.

<u>Comparison with jointed nonreinforced concrete pavement design.</u> An overlay thickness determined in accordance with the FAA rigid overlay design procedure[9] is presented here for comparison. All conditions for design are the same as those for the CRC overlay design example. The thickness of jointed nonreinforced concrete pavement ($R = 700$ psi) that is required over 8 in. of unstabilized granular subbase with a k of

300 psi/in. for 4428 annual B-727-200 departures (168 kips MGW) is 13.4 in. Then this value of h (required single-slab nonreinforced jointed concrete pavement thickness) is used to determine the required jointed nonreinforced concrete overlay thickness. The overlay thickness thus determined is 9.4 in. The CRC overlay thickness is 8.9 in. This represents a reduction from the jointed nonreinforced concrete overlay design of 9.4 - 8.9 = 0.5 in. The reduction amounts to about 5 percent in this case.

DESIGN PROCEDURES AND EXAMPLES - MILITARY AIRFIELDS

SLAB-ON-GRADE

DESIGN PROCEDURE

The flowchart in Figure 13 applies to the design procedure for military airfields.

Site investigation. The site investigation shall be accomplished in accordance with applicable parts of Departments of the Army and Air Force manual TM 5-824-3/AFM 88-6, Chapter 3.[8] This manual references other applicable publications for various special conditions, such as frost conditions, etc.

Design parameters - new pavement.

a. Material properties. The material properties for use in this design procedure include the properties of the concrete, subbase material, subgrade, and reinforcement. The quality of materials and concrete mixes, control tests, methods of construction, and quality of workmanship are governed by the Department of Defense Military Construction Guide Specification for concrete pavements, MCGS 02611.[16] The design concrete flexural strength shall also be determined in accordance with MCGS 02611.[16] The tensile strength of the concrete may be estimated as:[11]

$$f_t \simeq \frac{R - 210.5}{1.02} \qquad (3 \text{ bis})$$

The concrete modulus of elasticity is assumed to be 4×10^6 psi, unless the designer has reason to expect that the modulus will be significantly different than that. In the latter case the modulus shall be determined from a flexural test, as specified in Test Method CRD-C 21-58.[12] The design value shall then be the mean value of the available test results. The design allowable stress in the reinforcement steel shall be based on the relation[1]

$$f_s = 0.75 f_y \qquad (4 \text{ bis})$$

The modulus of elasticity for stabilized subbase materials shall be chosen from a number of moduli as determined from the test method published as Appendix H of Reference 13 for

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cement-stabilized soil or Appendix B of Reference 14 for
bituminous-stabilized soil. The test temperature for asphalt
stabilized materials must be closely controlled at or near the
expected average in situ temperature of the stabilized layer.
If no estimate of the temperature is available, a test
temperature of 77° F (20° C) is suggested. The modulus of
soil reaction, k , shall be determined for the subgrade in
accordance with MIL STD 621A, Method 104.[15]

b. Aircraft traffic. Aircraft traffic considerations account
for the number, type, and load characteristics of the air-
craft traffic for which the pavement is to be designed. The
methods to be used for determining these are given in TM 5-
824-1/AFM 88-6, Chapter 1[17] and TM 5-823-3.[18]

c. Pavement performance criteria. The pavement performance
criteria for CRC pavement design for military airfields are
the same as those for civil airports discussed previously.

d. Allowable stress. The nomographs in Figures 14-17 are to be
used for determining the allowable concrete stress for a CRC
pavement. Development of these nomographs has been previously
discussed.

Subbase design and composite k-value. The site investigation
and materials characterization shall furnish information necessary for
subbase design analyses and for selection of composite design k-values
for use in slab stress analyses.

a. Treatment of the subgrade. In addition to mechanical compac-
tion of the natural subgrade, stabilization by chemical treat-
ment may be warranted. Chemical stabilization (lime, cement,
and fly ash) of the subgrade should be considered when the
potential exists for detrimental environmental effects;
however, care must be taken to assure that the stabilized
material meets durability requirements contained in
TM 5-822-4.[19]

b. Subbase layers. Subbase layers for CRC airfield pavements
shall be stabilized with cement, asphalt, or special materials
approved by the Office, Chief of Engineers.* Either subbase
type may be preselected for use in subsequent thickness
designs or designs may be generated for alternate subbase
types for economic or performance potential comparisons.
All new CRC pavements must include a minimum 4-in. thickness
of the stabilized subbase meeting durability requirements
contained in TM 5-822-4.[19]

---

* Directorate of Military Construction, Engineering Division.

c. **Composite design k-value.** The composite design k-value is selected by entering the "Composite k-Value Chart," Figure 18, with the k-value that has been determined for the natural subgrade. Note that the maximum composite k-value allowed is 500 psi/in.

Slab thickness design procedure.

a. There are three basic phases of the slab thickness design procedure:

(1) Determination of design traffic (aircraft type, passes, load, etc.).

(2) Determination of allowable tensile stress in the PCC slab.

(3) Selection of the required slab thickness.

Because the allowable concrete stress determination is dependent on the subbase design, alternative subbase designs should be evaluated for any project.

b. **Design aircraft traffic.** The design requirements shall include the number of passes and gross weight of the design aircraft (light-, medium-, heavy-load, or shortfield design).[17] The design chart in this procedure is based on maximum gross weight of the design aircraft, as contained in Table 4. Thus, for design weights less than the maximum gross weight the allowable stress that is obtained from Figure 14, 15, 16, or 17 must be multiplied by the ratio of the maximum gross weight to the design weight, $\frac{MGW}{DW}$, before entering the design chart in Figure 27. In order to utilize the stress analysis charts (Figures 14-17), the design number of aircraft passes must be converted to stress repetitions. To do this, divide the number of passes by the appropriate aircraft repetition factor for the design aircraft (Table 5).

c. **Allowable concrete stress.**

(1) The modulus of soil reaction, k , of the natural subgrade is determined by plate bearing test using MIL STD 621A, Test Method 104.[15]

(2) The subbase modulus of elasticity should be determined in the manner outlined in Appendix H of Reference 13 or Appendix B of Reference 14.

(3) After the subgrade k and the subbase modulus of elasticity have been obtained, the composite k on top of the subbase is determined from Figure 18.

(4) Using the design concrete flexural strength, the design stress repetition level, and the composite k-value, enter

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Table 4

Aircraft Data - Military Airfields

Type Design	Design Aircraft	Maximum Gross Aircraft Weight, kips	Maximum Main Gear Tire Load, kips
Light Load	F-4	60	27.0
Shortfield	C-130	175	39.4
Medium Load	C-141	320	36.0
Heavy Load	B-52	480	54.0

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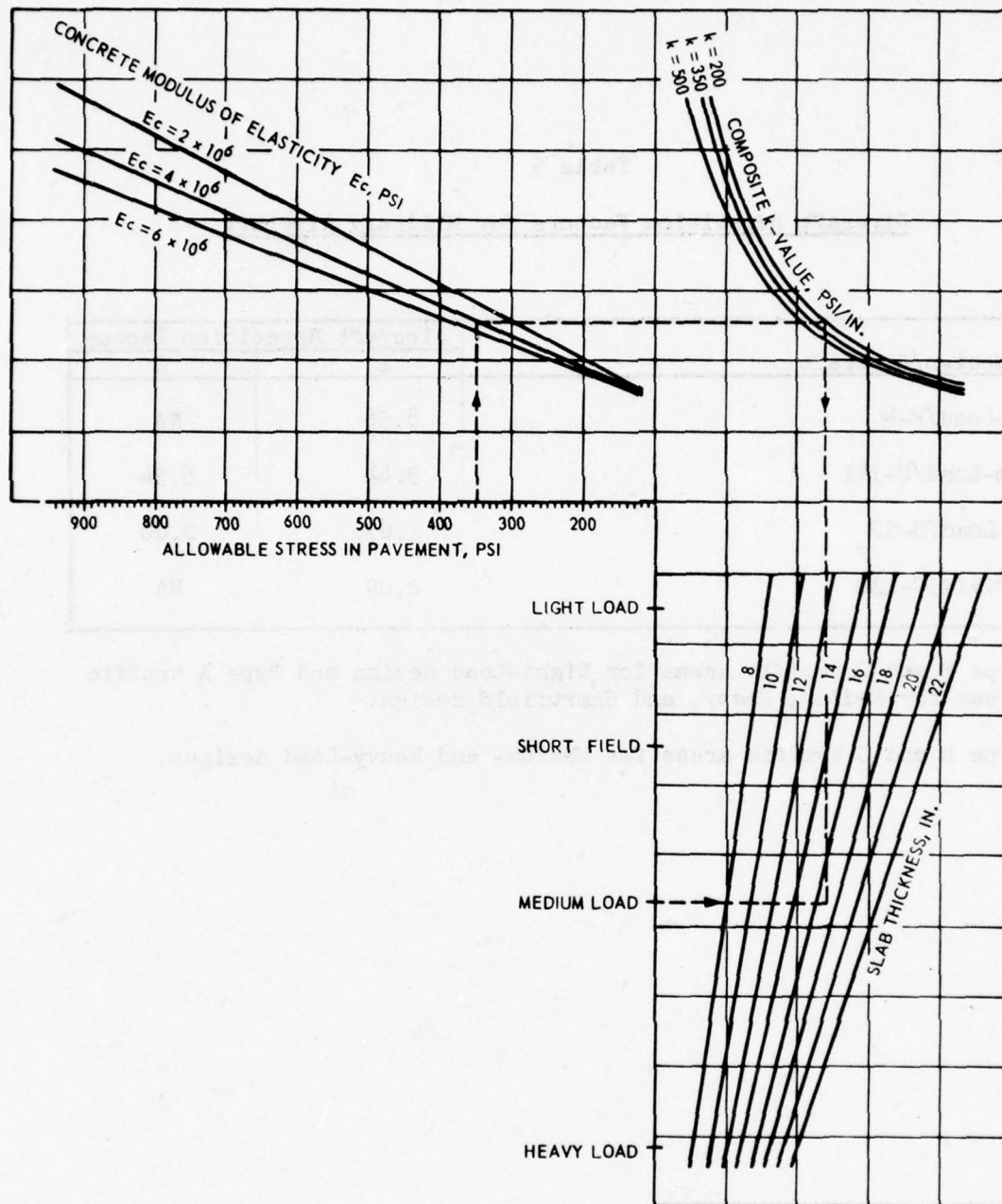
Figure 27. CRC pavement thickness design chart for military airfields[1]

Table 5

Aircraft Repetition Factors for Military Aircraft

Type Design/Aircraft	Aircraft Repetition Factor	
	1	2
Light-Load/F-4	8.58	NA
Medium-Load/C-141	3.44	6.34
Heavy-Load/B-52	1.63	2.00
Shortfield/C-130	2.09	NA

1 - Type B and C traffic areas for Light-Load design and Type A traffic areas for Medium, Heavy, and Shortfield design.

2 - Type B and C traffic areas for Medium- and Heavy-Load designs.

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the appropriate stress analysis chart (Figures 14-17).
Interpolation between the charts is possible for inter-
mediate values of k . A straight line between the stress
repetition level and the design concrete flexural strength
crosses the allowable concrete stress scale at the stress
value for those conditions. It is cautioned that the
stress repetition level is dependent upon the aircraft
repetition factor which in turn is dependent upon the type
traffic area. For instance, if the desired design is for
medium-load and Type A traffic area, enter the stress
analysis nomograph with the number of stress repetitions
determined from dividing the design pass level by the air-
craft repetition factor from the column labeled "1" in
Table 5. Likewise, if the design is for a Type B traffic
area for the same aircraft, the design passes are divided
by the aircraft repetition factor from Column 2 of Table 5
to obtain stress repetitions. It is also pointed out that,
for Type C traffic areas, the design load is reduced by
25 percent unless otherwise specified in the design
directive.

d. Slab thickness. The slab thickness required for the design
traffic is now determined from the design nomograph (Fig-
ure 27). As an example for reading the nomograph, suppose
the allowable concrete stress derived from Figure 14
(k ≤ 200 psi/in.) is 350 psi, the concrete modulus of
elasticity is 4×10^6 psi, and the design is for medium
load. Then, following the dashed arrows in Figure 27,
find the design CRC slab thickness to be 17 in.

DESIGN EXAMPLE AND
COMPARISONS - NEW PAVEMENT

Example design problem. The example problem is to prepare a
thickness design for a Type A traffic area at a large military base.
A medium-load pavement is to be designed for 50,000 passes of the
C-141 aircraft (320 kips gross weight). The concrete is to have a
design flexural strength of 700 psi. The top 8 in. of the subgrade
is to be lime treated. The subbase is to be 9 in. of cement-stabilized
material with an E_{SB} = 200,000 psi. Frost, drainage, or settlement
problems are nonexistent or minimal and need not be considered for this
problem.

a. Design traffic. The aircraft repetition factor for a Type A
traffic area for the C-141 is 3.44 from Table 3. Thus, the
total number of stress repetitions is $\frac{50,000}{3.44}$ = 14,535 (use
1.5×10^4).

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b. <u>Allowable stress in slab.</u> The k-value for the natural sub-grade is 110 psi/in. From Figure 18 the composite k-value on the top of the subbase is found to be 350 psi/in. Next, enter the appropriate allowable concrete stress nomographs to determine the allowable stress. Because the composite k is 350 psi/in., enter <u>both</u> Figure 15 (k = 300 psi/in.) and Figure 16 (k = 400 psi/in.) and interpolate between the two values of the allowable concrete stress. The actual value from Figure 15 is 530 psi, and that from Figure 16 is 580 psi. Therefore, the interpolated value is $\frac{530 + 580}{2} = 555$, or say 560.

c. <u>Design slab thickness.</u> Since E_c is 4×10^6 psi, Figure 21 now yields a design CRC pavement thickness of 10.6 in.

<u>Comparison with conventional rigid pavement design.</u> A thickness design based on the same parameters as the CRC example just presented has been determined by following the present CE-Air Force design procedure for jointed pavement.[8] The design medium-load (C-141) traffic on a Type A traffic area results in a jointed nonreinforced concrete thickness of 10.4 in. This means that the 10.6 in. CRC pavement design is about the same as the conventional jointed nonreinforced concrete thickness for these design conditions. For another comparison note that for jointed reinforced concrete pavement, with 0.3 percent steel, a thickness of 7.8 in. is required. Thus, the reduction allowed for jointed reinforced concrete pavement is 10.4 - 7.8 = 2.6 in., or about 25 percent.

OVERLAY DESIGN

DESIGN PROCEDURE

Figure 20 also applies to the design of CRC overlays for military airfields. This procedure is applicable only for CRC overlays of existing rigid pavements. If the existing pavement is a flexible pavement, the bituminous surface shall be considered to be a stabilized subbase, and plate bearing tests on top of the flexible pavement shall determine the k-value for use in the design procedure for new CRC pavement.

This procedure will use the thickness deficiency equation for a rigid overlay over a rigid base pavement with an asphalt concrete bond-breaker course between the two slabs.

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Based upon construction requirements a minimum thickness of 4 in. is recommended for CRC overlays. A bond-breaking course consisting of 1 to 3 in. of bituminous concrete or similar material shall be placed between the base pavement and the overlay slab.

Characterization of existing pavement. The conventional parametric evaluation methods shall be used for the existing pavement structure. It is important to obtain sufficient information to furnish a sound basis for the overlay design.

Design parameters - overlays.

a. Material properties. Details of the data required and the methods to be used to obtain that data are found in TM 5-824-3/AFM 88-6, Chapter 3.[8] The material properties necessary for the overlay design are: existing pavement thickness, the k-value of the subgrade (or subbase, if one exists), and the design flexural strength of the overlay concrete. Commonly evaluated soil characteristics of the subgrade and/or subbase include: (1) gradation, (2) moisture, (3) specific gravity, (4) liquid and plastic limits, (5) density, and (6) moisture-density relationships. The structural condition of the existing rigid pavement must be determined. Strength tests on the existing concrete are not required unless it is indicated that the flexural strength of the existing pavement may be substantially less than that of the overlay $(R_o - R_e \geq 100$ psi$)$. Likewise, determination of the modulus of elasticity of the concrete in the base pavement is not necessary unless it is suspected that $|E_o - E_e| > 1 \times 10^6$ psi. A visual examination will be necessary to determine the structural condition of the base pavement prior to the overlay.

b. Aircraft traffic and pavement performance criteria. These factors are considered in the same way for CRC overlays as they are for new pavements, which have been previously discussed.

Design based on equivalent thickness.

a. Input parameters. The design of a concrete overlay on a rigid pavement requires an assessment of the structural integrity of the existing rigid pavement, and then, the support which the existing pavement will provide for the overlay. The condition factor must be assigned based on a pavement condition survey (visual inspection). Although the selection of a condition factor is a judgment decision which is somewhat arbitrary, the following values should provide some guidance for assessment of the condition factor.

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C = 1.0 for existing pavement in good condition—some minor cracking, but no structural defects.

C = 0.75 for existing pavement containing initial corner cracks due to loading, but no progressive cracking or joint faulting.

C = 0.35 for existing pavement in poor structural condition—badly cracked or crushed and faulted joints.

The three conditions discussed above are used to illustrate the condition factor rather than to establish fixed values. Conditions at a particular location may require the use of an intermediate value of C within the recommended range. The thickness of the existing concrete pavement, h_e, is also necessary for use in this design procedure. It can be measured directly in test pits or on extracted cores. The thickness of a single-slab pavement, h, that would be required over the existing subgrade (or subbase if one exists) for the design conditions, and the thickness of CRC pavement equivalent to the thickness of existing jointed concrete pavement, h_e', must be determined according to the design procedure for new CRC pavement.

b. <u>Design equation.</u> The equation that shall be used for design of CRC overlays is:

$$h_o = \sqrt{h^2 - C h_e'^2}$$ (5 bis)

c. <u>Design procedure.</u> After the condition survey and the existing pavement characterization, the value for C is chosen and h_e is known. The design life of the existing jointed pavement may be found by working backward from the pavement thickness scale and forward from the flexural strength scale through design charts as shown in Figures 28-31. The design life in terms of aircraft passes may be interpolated between the traffic lines at the point of intersection of the lines obtained by working through the design curve. The aircraft passes may be converted to stress repetitions by dividing by the aircraft repetitions factor obtained from Table 5. Next, determine h and h_e' by using the design procedure for new CRC pavement. Finally, determine the design value for h_o from Equation 5 above. Concomitantly, it should be noted that reinforcement in the existing concrete slab is neglected in the overlay section. Should the case arise where a CRC pavement is to be overlaid, the thickness of the existing CRC pavement is used directly in Equation 5.
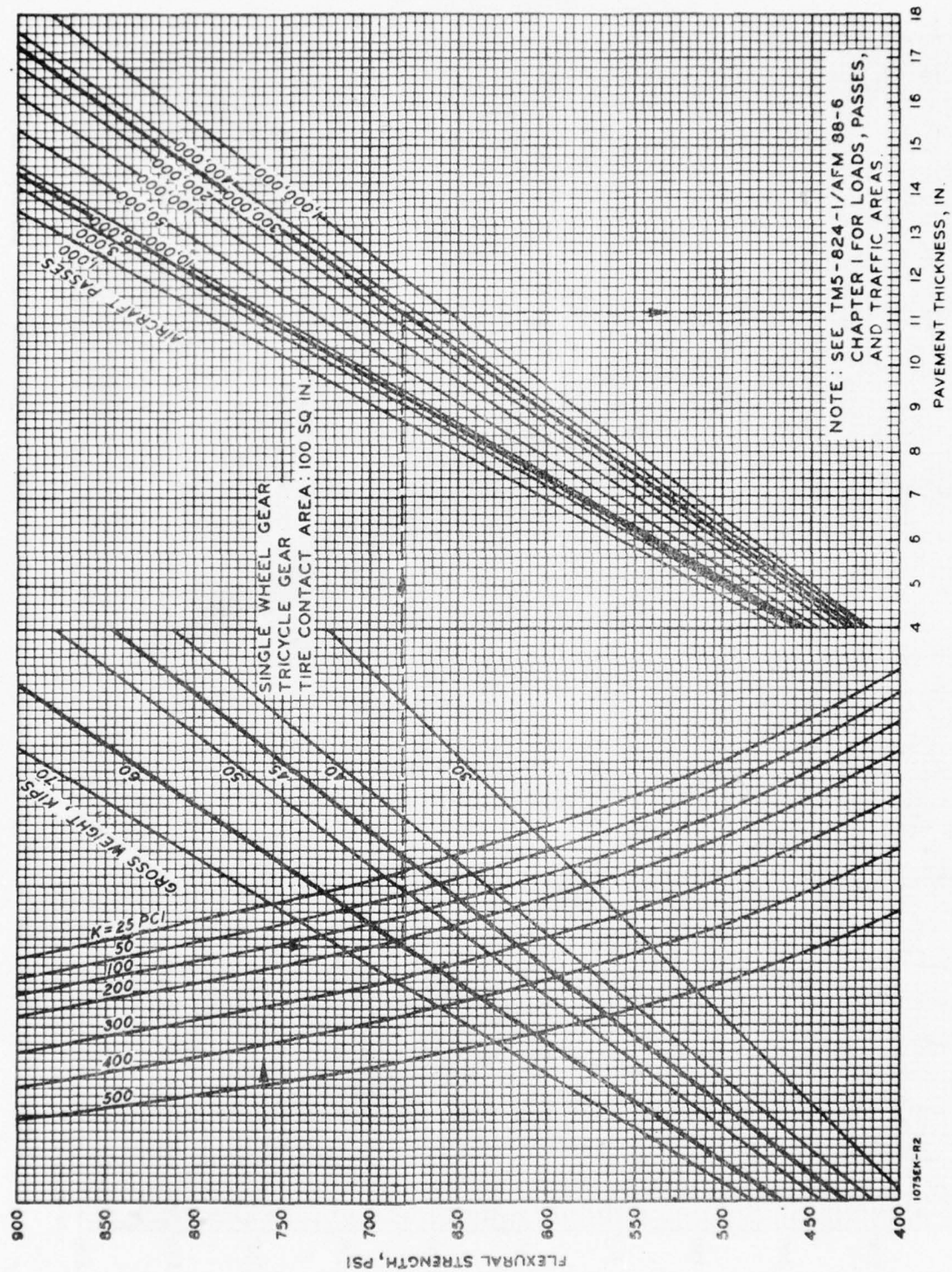
70

Figure 28. Nonreinforced rigid pavement design curves for light load pavements
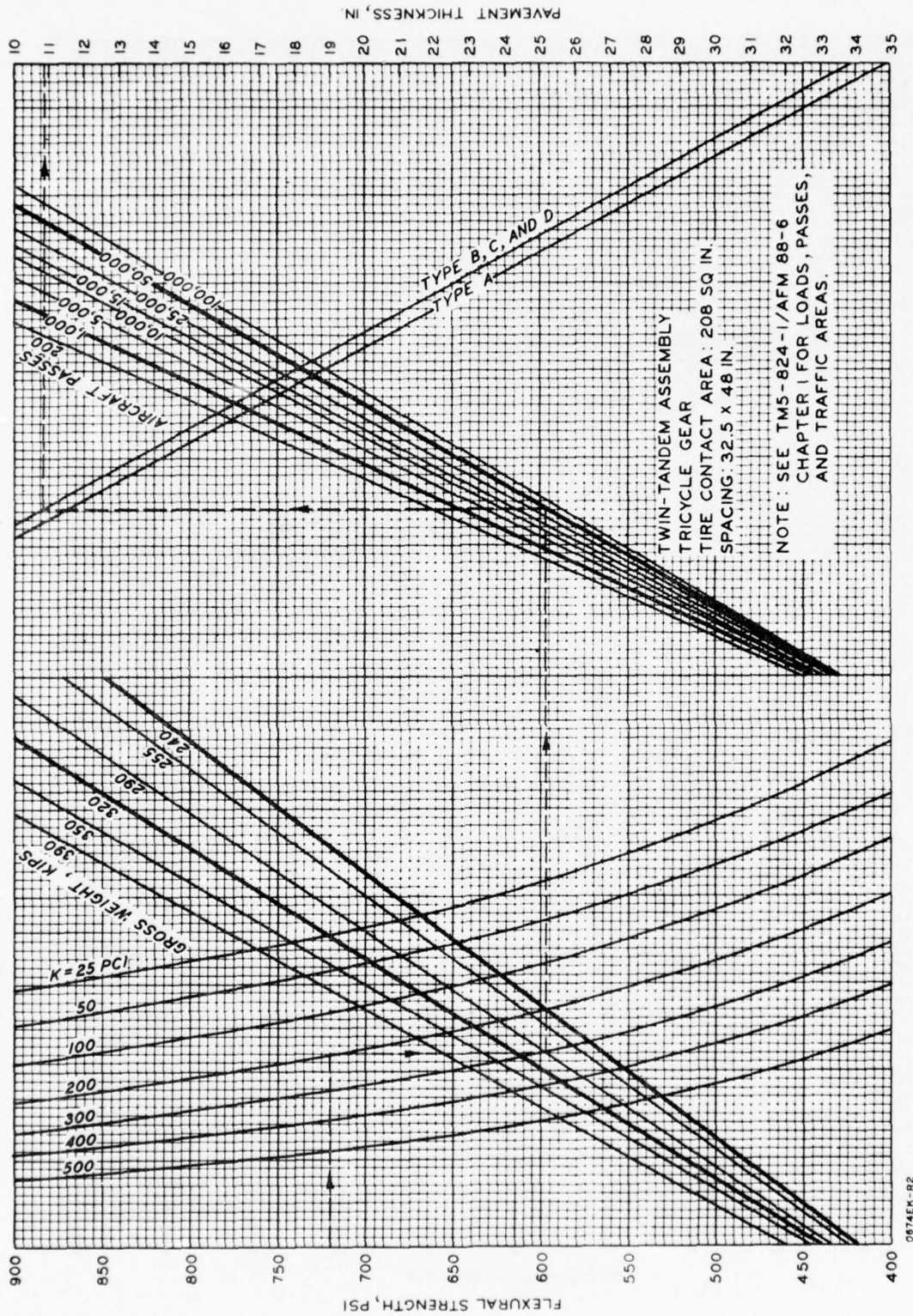
71

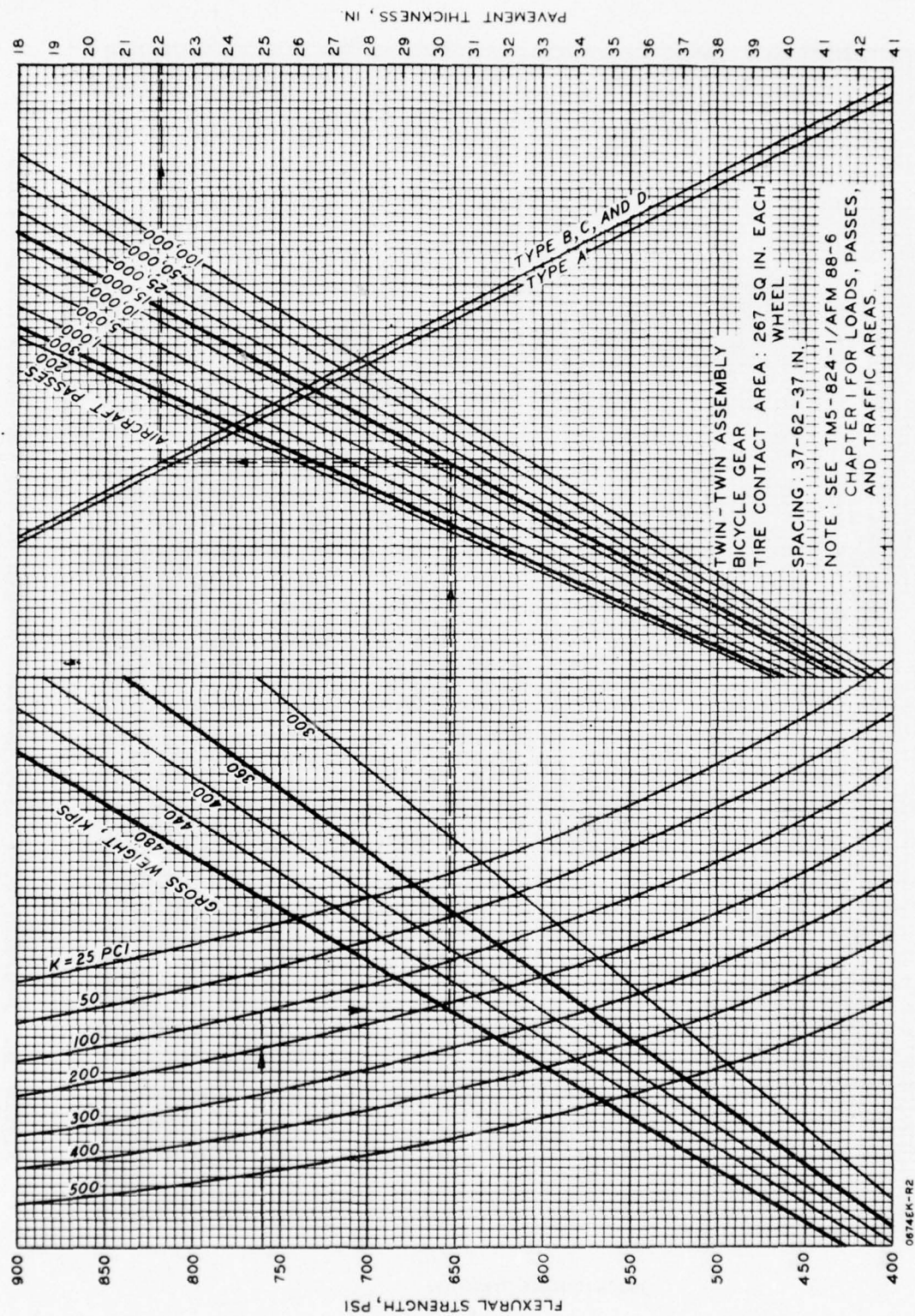Figure 29. Nonreinforced rigid pavement design curves for medium load pavements

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Figure 30. Nonreinforced rigid pavement design curves for heavy load pavements

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Figure 31. Nonreinforced rigid pavement design curves for shortfield pavements

DESIGN EXAMPLE AND
COMPARISON - OVERLAYS

Example design problem. A thickness design is desired for a CRC
overlay. The design traffic conditions are medium-load (C-141 aircraft,
320 kip MGW), Type A traffic area, and 50,000 passes. An 8-in. crushed
stone subbase exists with a k of 300 psi/in. The existing pavement
is 10-in. JPCP with a condition factor, C , of 0.75. The overlay con-
crete will have a design flexural strength, R - 700 psi, and modulus
of elasticity, $E_c = 4 \times 10^6$ psi. (Assume no significant difference in
flexural strength and modulus of elasticity between existing and overlay
slabs.)

a. Required CRC single-slab thickness. With the k-value of
300 psi/in., enter Figure 15 directly to determine the
allowable concrete stress. The allowable concrete stress
for $1.5 \times 10^4 \left(\frac{50,000}{3.44}\right)$ stress repetitions, from Figure 15
is approximately 530 psi. Next, enter Figure 27 and find
that the required thickness, h , is 11.1 in.

b. Equivalent CRC slab thickness. From the vertical thickness
scale on Figure 29 work backwards to the Type A traffic area
line and project a vertical line downward. With R = 700 psi,
k = 300 psi/in., and a gross aircraft weight of 320,000 lb,
work through the curve from the flexural strength scale to
the point of intersection with the vertical projection
previously described. This is illustrated in Figure 29 and
by interpolation a traffic volume of 14,000 passes is ob-
tained. This is converted to stress repetitions by dividing
14,000 by 3.44 (from Table 5) which yields approximately
4100 stress repetitions. With flexural strength, R = 700
psi and 4100 stress repetitions the allowable stress is ob-
tained from Figure 15 as 605 psi. Figure 27 is entered and
an equivalent CRC thickness of 10.2 in. is obtained.

c. Calculation of overlay thickness. For calculating h_o use
h = 11.1 in., C = 0.75 , and $h_e' = 10.2$ in. in Equation 5.
The calculated overlay thickness is 6.7 in.

Comparison with conventional rigid overlay design. For compari-
son, a thickness design based on the same parameters as the CRC example
just described is developed here by following the present rigid pavement
overlay design procedure for military aircraft.[8] The jointed nonrein-
forced concrete single-slab thickness, h , that is necessary for those

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parameters is 11.0 in. Therefore, from Equation 5, the resulting
overlay thickness is 6.7 in., which is the same as for the CRC overlay.
However, it should be noted that the minimum nonreinforced jointed
concrete overlay thickness is 8 in. for multiple-wheeled gears.[8]

SPECIAL PROVISIONS

TERMINAL DESIGN

The ends of CRC pavement will experience large movements if unrestrained or they will exert considerable forces on abutting structures if restrained. In order to protect abutting pavements and structures from damage, the end of the CRC pavement must be isolated or the movement restrained. Experience has shown that it is practically impossible to completely restrain or to completely isolate the end of a CRC pavement. The most successful scheme appears to be one which utilizes both concepts; i.e., partial restraint and limited available expansion space.

End anchorage and/or expansion joints must be provided when CRC pavement is not continuous through intersections or when it abuts a structure. It is important that an efficient terminal treatment system be used at the intersection of new runways and taxiways with existing runways and/or taxiways. Special terminal treatments are normally not used at free ends of CRC pavement. Expansion joints without anchorage have normally been used for CRC overlays. However, this does not preclude the use of an anchor system if it can be shown to be more economical to partially restrain the movement and provide only a limited expansion space rather than try to accommodate the total movement.

Selection of a terminal treatment system is largely a matter of preference of the designer. There are numerous terminal treatment systems which have been satisfactory for highway pavements.[1,20-23] The two most successful appear to be the anchor lug and the wide-flange beam joint. There are other anchorage systems such as piles or joints like the "finger type bridge joints," which behave similarly but their usage has not been as extensive. The anchor lug and the wide-flange joint systems have been used on CRC airport pavements and overlays. Both of these have performed satisfactorily.

Typical sections of the anchor lug and wide-flange beam systems are shown in Figure 32.

EXPANSION JOINTS

T

ANCHORAGE
LUGS

SLEEPER
SLAB

17'   17'   17'   17'

TERMINAL ANCHORAGE TREATMENT

CRCP   REINFORCEMENT

T

6"

3'-0"

6"

2'-0"

ANCHORAGE LUGS

CONTINUOUSLY REINFORCED
CONCRETE PAVEMENT

3/4" GROOVE, HOT-POURED SEAL   9" OR 10" PAVEMENT

HEAVILY
GREASED

1/4" GROOVE, HOT-POURED SEAL

1" EXPANSION JOINT MATERIAL
(STYROFOAM OR EQUIVALENT)

10"

6"

< 5'-0"
TAPER

BOND BREAKER

X   X

LOAD TRANSFER
DOWELS

EXPANSION JOINTS

10'-0"

NO. 4 BARS 20'-6" @ 12" O. C.
NO. 5 BARS 23'-8" @ 8" O. C.

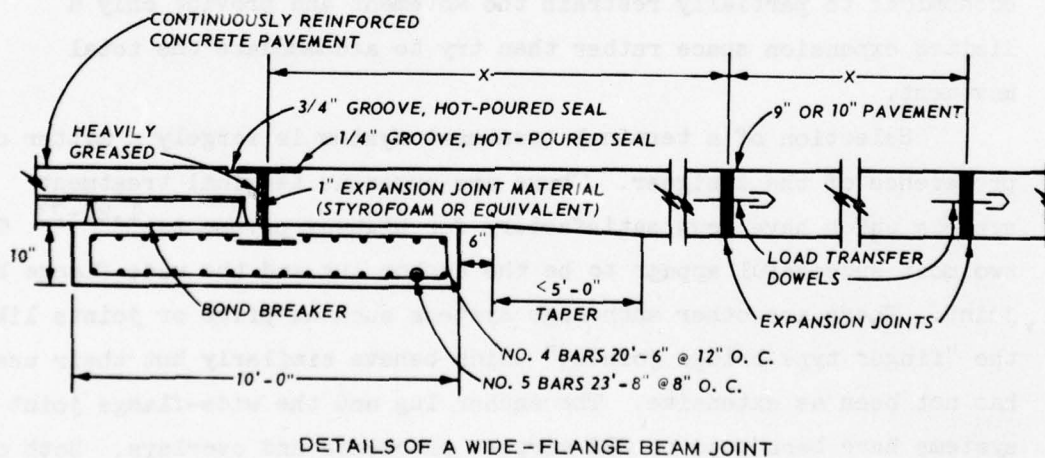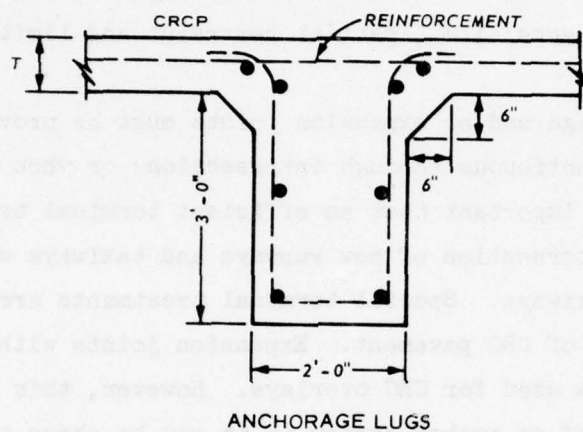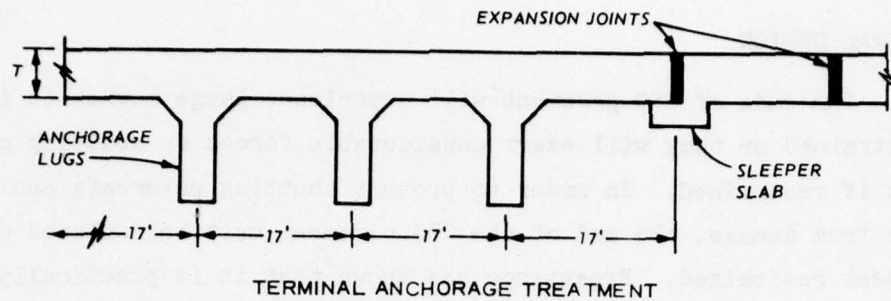DETAILS OF A WIDE-FLANGE BEAM JOINT

Figure 32.   Examples of CRC pavement terminal treatments[1]

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REINFORCEMENT

STEEL

The reinforcing steel must have deformations or deformation properties adequate to ensure that crack widths are controlled at the steel stress design levels. This criterion should not be compromised for any reason. Although several different sizes and grades of deformed bars are satisfactory for use in CRC pavement, the type selected is dependent on availability and construction methods. Generally, longitudinal reinforcing bars are deformed billet bars with 60,000 psi minimum yield strength conforming to ASTM Designation A-615, grade 60.[24] However, ASTM Designation A-615, grade 40, should be used for transverse steel or tie bars if bending is anticipated during construction. If coupled tie bars are permitted stronger steels may be used, provided the coupling develops the full potential of the bar.

Welded deformed steel wire fabric conforming to ASTM A 497[24] may be used. Wire fabric with wires which are not deformed should not be used.

LONGITUDINAL REINFORCEMENT

The required amount of longitudinal reinforcing steel in a CRC pavement must be checked by three methods. The percentage of longitudinal reinforcing steel must be equal to or larger than the largest amount computed with the following three criteria:

a. The AASHO design equation for continuous reinforcement.[25] This is an empirical relationship which insures that the amount of steel is sufficient to keep transverse shrinkage cracks tightly closed.

b. The amount of steel required to resist temperature-induced stresses.[26]

c. The amount of steel required to resist stresses induced by shrinkage of concrete.

The first check of longitudinal reinforcement requirements is made using the nomograph shown as Figure 33, which relates the required steel percentage to:

a. The allowable working stress of the steel.

(3) FRICTION FACTOR F

2.0 1.5 1.0

(4) REQUIRED STEEL PERCENTAGE P_s, %

0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.5 2.0

EXAMPLE PROBLEM:
$f_t = 300$ PSI
$f_s = 45$ KSI
F = 1.5
ANSWER: $P_s = 0.66\%$

PIVOT LINE

(2) ALLOWABLE STEEL STRESS f_s, KSI

70 60 50 52.5 48.75 45 40 37.5 30 20

SOLVES $P_s = (1.3 - 0.2\ F)\ \dfrac{f_t}{f_s}$

(1) TENSILE STRENGTH OF CONCRETE f_t, PSI

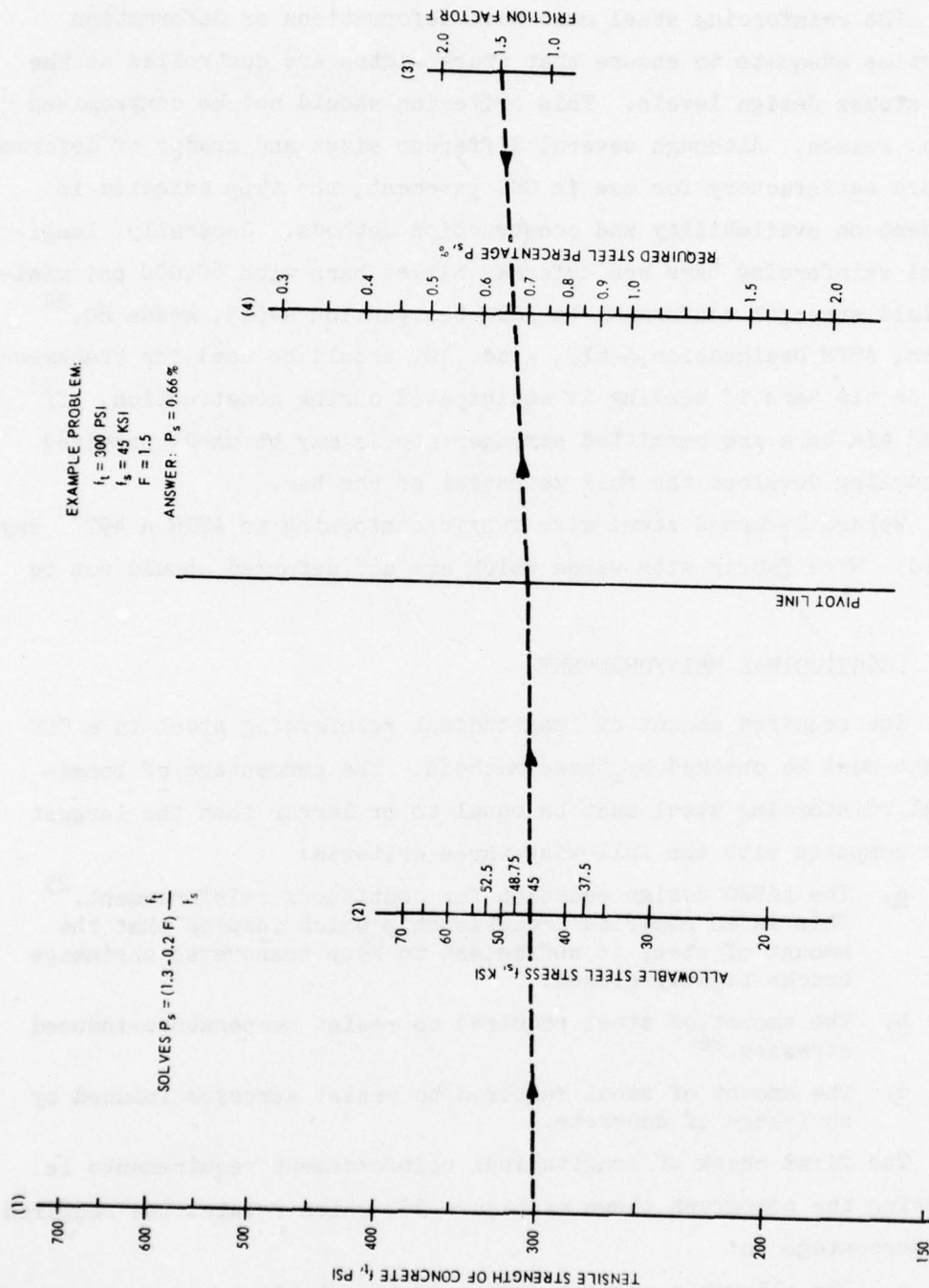700 600 500 400 300 200 150

Figure 33. Design chart for continuous longitudinal reinforcement[1]

    <u>b</u>.   The tensile strength of the concrete (at 7 days).

    <u>c</u>.   The friction factor, F , of the subbase, which may be obtained from Table 6.

The nomograph solves the equation developed for the <u>AASHO Interim Guide for Design of Pavement Structures.</u>[25]

The friction factor for asphalt stabilization should be used for overlays of rigid pavements where a bond-breaking layer is used and for overlays of flexible pavements where the surface course is asphalt concrete. Should the flexible pavement have a porous friction course cover surfacing or some other form of surface treatment designed to improve skid resistance, then the friction factor for Bituminous Surface Treatment should be used.

The second check of required longitudinal reinforcement is made by solving Equation 6 which computes the percentage of steel needed to resist temperature-induced stresses.[26] The equation is:

$$P_s = \frac{100\ f_t}{2(f_s - \Delta T \alpha_c E_s)} \tag{6}$$

where

    P_s = required percent longitudinal reinforcement

    f_t = 7-day tensile strength of the concrete, psi

    f_s = working stress in the steel, psi

    ΔT = average temperature differential to which the pavement is expected to be subjected, degrees

    α_c = thermal expansion coefficient of the concrete

    E_s = modulus of elasticity of the steel, psi

Prior to the formation of a crack, the strains in the steel and the concrete are the same if complete bond is maintained between the two materials. When the tensile stress exceeds the strength of the concrete, a crack forms and all the stress is carried by the reinforcing steel. The third check for percent longitudinal reinforcement is the computation of the ratio of the concrete tensile strength to the steel strength. The equation is:

$$P_s = \frac{f_t}{f_s} \times 100 \tag{7}$$

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Table 6

Recommended Subbase Friction Factors
for Reinforcement Design

Subbase Type	Friction Factor*
Bituminous Surface Treatment	2.2
Lime Stabilization	1.8
Asphalt Stabilization	1.8
Cement Stabilization	1.8
River Gravel	1.5
Crushed Stone	1.5
Sandstone	1.2
Natural Subgrade	0.9

* These recommendations were adapted from Reference 22.

This is the required percentage longitudinal steel needed to prevent overstressing of the steel because of high-strength concrete which can result in large crack spacings.

The largest percentage of steel as computed with the above three methods is selected as the design percentage. The percentage of longitudinal steel shall in no case be less than 0.5 percent.

TRANSVERSE REINFORCEMENT

The transverse steel design will be based on the subgrade drag theory as outlined by McCullough.[27] The design variables are summarized into a transverse reinforcement design chart and shown in Figure 34.

Some continuously reinforced pavements for highways have been designed without transverse reinforcement. These pavements should perform satisfactorily unless longitudinal cracking occurs. However, transverse reinforcement is recommended for all CRC airport pavements because if longitudinal cracking occurs, the transverse reinforcement will restrain lateral movement and maintain the slab continuity.

In addition to structural requirements, transverse steel is beneficial as a construction expedient. It should be utilized to maintain proper horizontal spacing and vertical location of longitudinal bars.
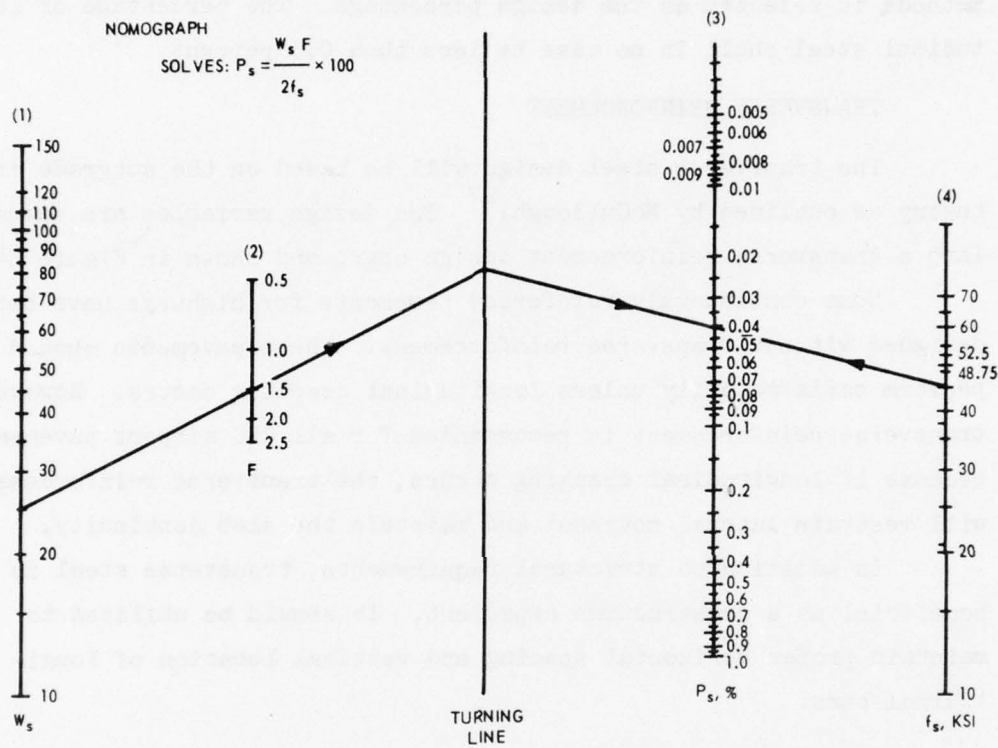
REINFORCEMENT DETAILS

The reinforcement detailing chart shown in Figure 35 shall be used to select a series of alternate bar or wire spacing designs for reinforcement in both directions. The bond area-to-concrete volume ratio should be calculated for each proposed design. This ratio shall be computed using:[26]

$$R_{av} = \frac{4A_b}{dA_c} \tag{8}$$

where

R_{av} = the ratio of bond area to concrete volume, in.^{2}/in.^{3}

A_b = area of one steel bar, in.^{2}

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NOMOGRAPH

$$\text{SOLVES: } P_s = \frac{W_s F}{2 f_s} \times 100$$

(1)

- 150
- 120
- 110
- 100
- 90
- 80
- 70
- 60
- 50
- 40
- 30
- 20
- 10

W_s

(2)

- 0.5
- 1.0
- 1.5
- 2.0
- 2.5

F

TURNING
LINE

(3)

- 0.005
- 0.006
- 0.007
- 0.008
- 0.009
- 0.01
- 0.02
- 0.03
- 0.04
- 0.05
- 0.06
- 0.07
- 0.08
- 0.09
- 0.1
- 0.2
- 0.3
- 0.4
- 0.5
- 0.6
- 0.7
- 0.8
- 0.9
- 1.0

P_s, %

(4)

- 70
- 60
- 52.5
- 48.75
- 40
- 30
- 20
- 10

f_s, KSI

EXAMPLE PROBLEM:

$W_s = 25$ FT

$F = 1.5$

$f_s = 45,000$ PSI

ANSWER: $P = 0.04$ %

WHERE:

P_s = REQUIRED STEEL PERCENTAGE, %

W_s = WIDTH OF SLAB, FEET

F = FRICTION FACTOR OF SUBGRADE, SUBBASE, OR STRESS-RELIEVING LAYER

f_s = ALLOWABLE WORKING STRESS IN STEEL, PSI (0.75 OF YIELD STRENGTH RECOMMENDED, THE EQUIVALENT OF SAFETY FACTOR OF 1.33)
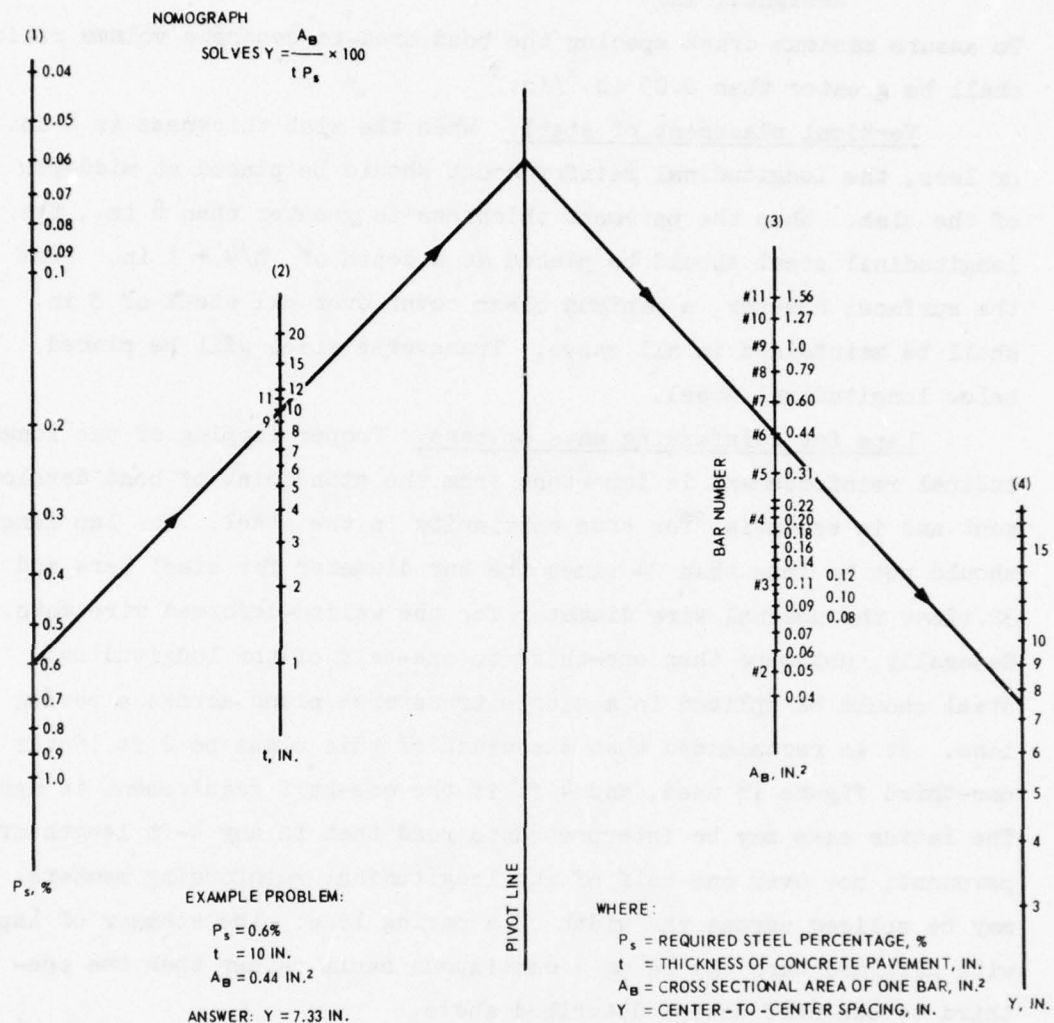
Figure 34. Transverse reinforcement design chart[1]

Figure 35. Reinforcement design detail chart[1]

d = diameter of bar or wire, in.

A_c = area of concrete perpendicular to reinforcement being designed, in.^{2}

To assure minimum crack spacing the bond area-to-concrete volume ratio shall be greater than 0.03 in.^{2}/in.^{3}

Vertical placement of steel. When the slab thickness is 8 in. or less, the longitudinal reinforcement should be placed at middepth of the slab. When the pavement thickness is greater than 8 in., the longitudinal steel should be placed at a depth of $h/4 + 1$ in. from the surface; however, a minimum clear cover over all steel of 3 in. shall be maintained in all cases. Transverse steel will be placed below longitudinal steel.

Laps for reinforcing mats or bars. Proper lapping of the longitudinal reinforcement is important from the standpoint of bond development and is essential for true continuity in the steel. The lap lengths should not be less than 24 times the bar diameter for steel bars and 32 times the nominal wire diameter for the welded deformed wire mats. Generally, not more than one-third to one-half of the longitudinal steel should be spliced in a single transverse plane across a paving lane. It is recommended that the width of this plane be 2 ft if the one-third figure is used, and 4 ft if the one-half requirement is used. The latter case may be interpreted to read that in any 4-ft length of pavement, not over one-half of the longitudinal reinforcing members may be spliced across the width of a paving lane. The stagger of laps with deformed bars may be on a continuous basis rather than the one-third to one-half detail described above.

JOINTS

Five types of joints are used in CRC pavements. These are (a) special terminal joints (wide-flange and bridge-type finger joints as discussed previously), (b) expansion joints (used as or in conjunction with terminal treatment procedures), (c) longitudinal construction joints, (d) longitudinal contraction joints, and (e) transverse construction joints. The special terminal joints have been discussed

previously in connection with terminal treatment systems, and will not be considered further. However, the last four listed above will be considered with particular emphasis on differences between CRC and jointed concrete pavements.

EXPANSION JOINTS

Details for expansion joints for CRC should be the same as those contained in FAA AC 150/5320-6B[9] and TM 5-824-3/AFM 88-6.[8] Thickened edge expansion joints will be used at intersections where slip between the pavements is required and doweled expansion joints will be used when transverse joints are used as part or all of the terminal treatment system.

LONGITUDINAL CONSTRUCTION JOINTS

Requirements for longitudinal construction joints for CRC are similar to those for jointed pavements in References 8 and 9. Keyed, keyed and tied, doweled, and thickened edge joints may be used as specified in the particular publication depending on whether the pavement is for a military or civil facility. The requirements for spacing of longitudinal joints and widths which can be tied should be commensurate with requirements for reinforced jointed pavements with percentages of steel equal to the amount of transverse steel. Tie bars for keyed and tied joints should be designed in accordance with procedures previously described for transverse reinforcement and the length should be 30 in. as required in References 8 and 9. Doweled joints should not be used when slip between abutting pavements will occur.

LONGITUDINAL CONTRACTION JOINTS

Longitudinal contraction joints will not normally be required in CRC pavements unless the paving lane width is greater than 25 ft or a number of paving lanes are tied together. Should longitudinal cracking prove to be a problem, provisions should be made to form a contraction joint at the locations necessary to control the cracking.

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Transverse steel should be carried through longitudinal contraction joints.

TRANSVERSE
CONSTRUCTION JOINTS

Transverse construction joints shall be designed to provide slab continuity by continuing the normal longitudinal steel through the joint. The normal longitudinal reinforcement should be supplemented by additional steel to provide adequate resistance to repeated shear and bending stresses. The best method of providing the additional steel is to add a 5-ft-long bar (the same size) between each pair of regular longitudinal bars. This practically doubles the amount of longitudinal reinforcement across the joint (see Figure 36). Thus, in most cases the
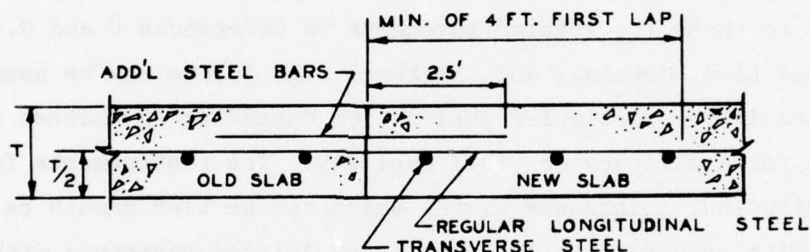

Figure 36. Details for transverse construction joints[1]

total percentage of steel will be 1 percent or greater. Normally, transverse construction joints are not sealed. This is because these joints usually perform and behave as conventional volume-change cracks that are present elsewhere in the pavement.

RECOMMENDATIONS

Because of limitations discussed previously, the procedures presented herein are recommended for use in the design of CRC airport and airfield pavements and overlays if the designer can tolerate damage that may result from deflection or other unspecified causes. The procedures presented provide designs which effectively account for the stress-related (cracking) failure mode. If the designer determines that the potential damage due to excessive deflection or other causes is unacceptable, it is recommended that the CRC pavement be designed as the same thickness as conventional nonreinforced jointed concrete pavement. CRC pavement would still have the advantages of no transverse joints, reduced maintenance, and improved ride quality.

Research should be undertaken to provide information which can be used to evaluate the utility and reliability of CRC pavements and overlays. Specific areas of needed research include:

a. Identification and description of additional failure modes (other than load-induced cracking), and determination of the feasibility of a design procedure that accounts for all of the failure modes. Distress associated with vertical deflections should receive special attention.

b. Use of nondestructive deflection measurements in characterizing existing pavements for CRC overlay design.

c. Improve the limiting stress performance criteria.

d. Identification and quantification of effects of environmental factors (temperature, moisture, and wind velocity) during and after construction and construction procedures on the performance of CRC pavements and overlays.

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